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PhD thesis in

The Attentional Boost Effect: What limits and what causes it? A behavioural and functional study in older adults, euthymic bipolar patients and healthy subjects.

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1. General Introduction

1.1. The Attentional Boost Effect

1.1.1. Introduction

Our world is full of information. To move adequately in it, we are forced to monitor more aspects of our reality simultaneously. However, our cognitive abilities are limited for their nature (Lavie, 2005). A well-known experimental paradigm in the literature about memory and attention that showed these limitations is the "*dual-task paradigm*", where participants are asked to perform two tasks at the same time. A lot of studies showed that when attention to one task increases, performance on the second task suffers (Pashler, 1994), meaning that the two tasks compete for the same resources within the cognitive system. Decades of work on dual-task performance and selective attention has provided clear and robust evidence that dividing attention across multiple tasks and stimuli impairs performance (Kahneman, 1973; Kinchla, 1992; Pashler, 1994), and that selective attention to one object often temporarily interferes with the ability to process other objects (Duncan, 1980; Dux & Marois, 2009; Raymond, Shapiro, & Arnell, 1992).

For example, Duncan (1980) asked participants to search for two briefly presented targets appearing either at the same time or at different times. Participants were more likely to miss a target in one location if they detected a simultaneously presented target in another location. Furthermore, work on the psychological refractory period (PRP) has shown that when two tasks share a limited capacity processing step (the ‘‘central bottleneck"), processing for the second task is delayed until processing for the first task is complete (Pashler, 1994). In memory studies, numerous experiments indicate that dividing attention between two tasks during the encoding phase negatively affects performance on a subsequent explicit memory test such as recognition, free recall and cued recall (Baddeley, Lewis, Eldridge, & Thomson, 1984; Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; Mulligan, 1998; 2008). It is therefore likely that the detection of task-relevant changes, as targets, draws attentional resources away from processing other information or performing other tasks ("*interference hypothesis"*).

More recently, there are growing evidence to suggest that a transient increase in attention to a task can improve the performance in a second task (Lin et al 2010; Swallow & Jiang, 2010). Seitz and Watanabe have shown that perceptual sensitivity to motion, that coincides with a target letter (but not with a distractor letter), increases following repeated pairings of target and motion over several days (Seitz & Watanabe, 2003). This task-irrelevant perceptual learning has been shown after long-training periods and in tasks in which the background motion was subthreshold (so learning was unconscious) and irrelevant to the participant's task. In the work of Lin et al. (2010), participants saw a short and briefly presented sequence of familiar scenes. A letter was presented in the centre of each scene, and participants reported the identity of the grey letter at the end of each trial. They were also shown a scene and asked to indicate whether it was presented during the trial. Their results showed that target detection enhanced short-term source memory for scenes. In general, these theories suggest that increasing attention in response to task-relevant changes in events may facilitate cognitive processing at the moment of the change (*"facilitation hypothesis"*).

1.1.2. The Attentional Boost Effect: a facilitatory effect of divided attention

Swallow & Jiang (2010) showed a paradoxical phenomenon whereby dividing attention in the encoding phase does not impair but, on the contrary, improves, performance in a later memory test. In their experiments, participants performed two continuous, unrelated, tasks at the same time. For the primary task, participants encoded, and tried to memorize, a long series of scenes (500ms/item) for a later memory test. For the secondary task, participants performed a detection task. The instructions were to press a key whenever an infrequent white square (target) appeared and ignored the more frequent black squares (distractor). Importantly, the square was completely unrelated to the scene. Approximately two minutes after completing the double-coding phase, the participants had to perform a 4-alternative forced-choice recognition test (4AFC) on the images. Participants were instructed to choose the exact image that was shown to them during the encoding phase (Figure 1.1). In agreement with the literature on the dual-task paradigm, in general when attention to one task increase, performance on the second task suffers. Based on these results, the detection of the task-relevant changes should draw attentional resources away from processing other information or performing other task (*"interference hypothesis"*). On the other hand, if increasing attention to a target leads to widespread increases in perceptual processing, then scenes that are presented at the same time as a target square should be better remembered than those presented with a distractor square ("*facilitation hypothesis"*).

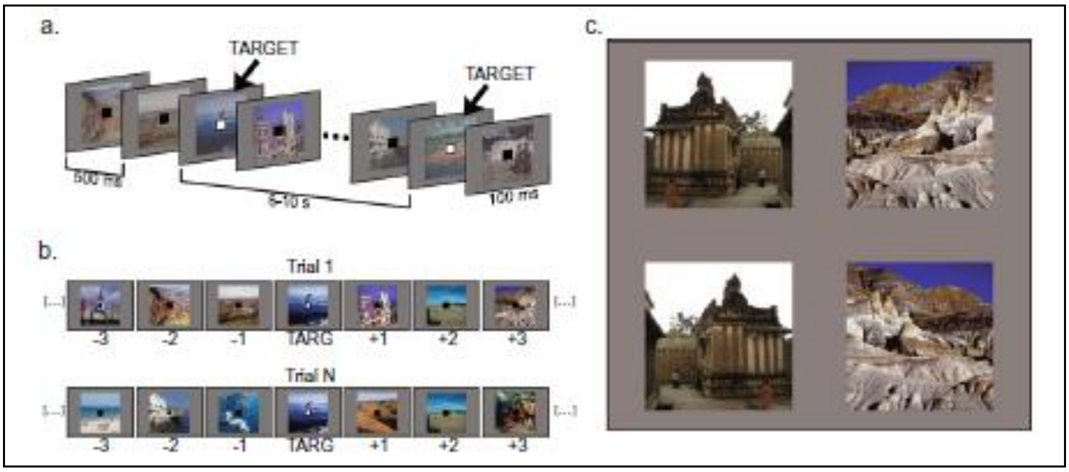

Figure 1.1. Representation of dual task encoding used in Experiment 1 by Swallow & Jiang (2010) (**a.**) Participants saw a long sequence of scenes with a white or black square in the centre. They had to memorize the scenes for a later test and press a key when they saw the white square. (**b.**) Target was always in the same position within the trial. (**c.**) Example of recognition test: participant had to choose the picture corresponding to the one seen in the encoding phase.

The results (Figure 1.2) showed that images that were presented in the encoding phase at the same time as the target (white square) were better recognized in the test phase than those presented with the distractors (black squares).

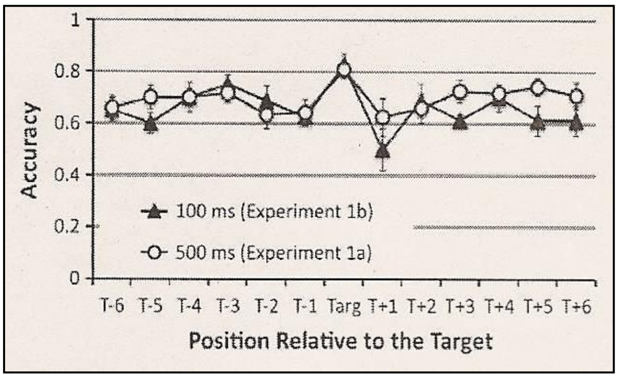

Figure 1.2. Proportions of Recognized Scenes depending on the Serial Position in relation to the target during encoding in Experiment 1 by Swallow and Jiang (2010). In Experiment 1a scenes lasted for 500 ms each, in Experiment 1b scenes lasted for 100 ms followed by a 400 ms blank. Bars represent standard errors.

According to Swallow & Jiang (2010), detecting an occasional target in a secondary task induces a transient attentional response when the target appears. This attentive orientation response could led to an increase in the available attentional resources, facilitating the processing and encoding of both the primary and the secondary task stimuli (pictures and squares respectively) in memory. Because the increase in attention due to the detection task promoted the performance in the encoding task, this phenomenon has been defined as "*Attentional Boost Effect" (ABE)*. Contrary to what was classically demonstrated in the dual task paradigms, increasing attention in a task can facilitate, rather than compromise, performance in another task (in agreement with the *facilitation hypothesis*).

The authors compared the results obtained in the Divided Attention (DA) condition with those obtained in a Full Attention (FA) condition (Swallow & Jiang, 2010, Exp. 3). They performed an experiment with the same characteristics as previously described, but this time the instructions were to memorize the pictures and ignore the squares. The results showed no advantage in the recognition task for the images encoded with target square. Indeed, scenes encoded in the target position were not better recognized than scenes encoded in distractor position (Figure 1.3).

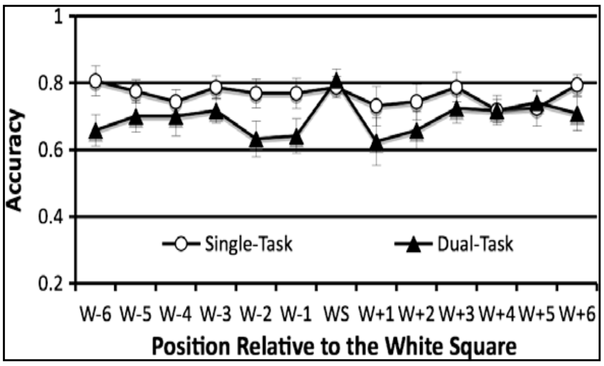

Figure 1.3. Accuracy of Memory for Image Identity as function of the Serial Position of the image during encoding in the single-task in Experiment 3 and during encoding of the dual-task in Experiment 1 by Swallow and Jiang (2010). Bars represent standard errors.

Since in these conditions the boost effect did not occur, Swallow & Jiang (2010) suggested that memory improvement in target condition in the first experiment was triggered by a change in the attentional demands of the detection task.

By comparing the results obtained in the FA condition with those previously obtained in the DA condition, it can be noted that the ABE is a relative effect. Observing the graph in Figure 1.3, there was no evidence of the dual task interference for the target condition because the accuracy level of the memory in the DA condition reaches those obtained by participants in the FA condition. In other words, the target detection in the first experiment overcomes the effects of interference due to the dual task condition. On the contrary, the classical dual task interference effect can be observed comparing the results in the distractor positions between the two attentional conditions: in the FA condition the accuracy level of the recognition was higher than that observed in the DA condition.

Observing their results, Swallow & Jiang (2010) assumed that the Attentional Boost Effect (ABE) reflects the combination of two attentional effects:

- an *attentional boost*: a facilitation to the primary task (the memory task) due to the transient increase in attention thanks to target detection in the secondary task (the detection task);

- and an *attentional competition*: an interference to the primary task due to the increase in the demand for attentive resources needed to monitor the colour of squares in the secondary task.

Swallow & Jiang (2010) tested this hypothesis in two different experiments. In the first one, the authors used a *colour-shape conjunction task* (Swallow & Jiang, 2010, Exp. 4). Participants were asked to press a key whenever a red "X" was presented in the centre of the screen. Distractors were other letters (Y, Z, V) that could be red or in other colours (blue, green, yellow) as well as "X" in these other colours. Results (Figure 1.4) showed that memory for scenes presented with target was higher compared to memory for scenes presented with distractor.

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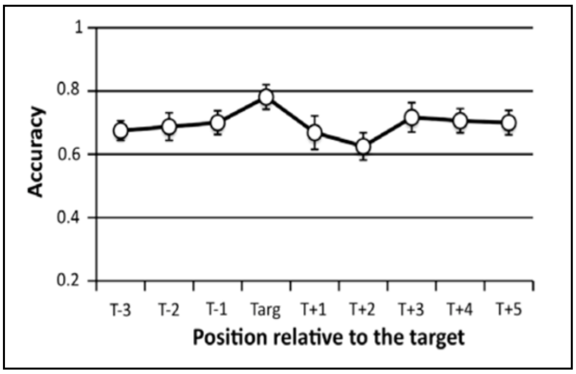

Figure 1.4. Accuracy of Memory for Image Identity as function of the Serial Position of image during encoding in the *colour-shape conjunction task* in Experiment 4 by Swallow and Jiang (2010). Bars represent standard errors.

The ABE was thus present when the targets were defined by the conjunction of two features, giving further evidence that the effect occurs when the attentional demands of the target-detection task briefly increased. However, the increase in the task difficulty of the conjunction-search task relative to the simple detection task seems to have reduced its magnitude, at least numerically (from *d* = 1.26 in the Exp. 1, to *d* = .706 in Exp. 4).

In the second experiment (Swallow & Jiang, 2010, Exp. 5), the authors used two different types of detection task, based on the response that was made to the target squares (red and green squares). In the *simple-detection task*, the participants pressed the spacebar whenever either the red or the green square appeared. In the *arbitrary-mapping task*, participants pressed one key ("r" key) for the red square and another key ("g" key) for the green square. No response was required for distractor squares (black squares) in either task. If the ABE was a compromise between an attentional competition and an attentional boost, an increase in the cognitive resources required to perform the secondary task (accessing the response mapping into working memory and selecting an arbitrary response as red is key "r" and green is "g" key) could eliminate the facilitation effect for the memory of the images encoded with the target. The results (Figure 1.5) showed that recognition accuracy for images presented with target was significantly higher than that for the images presented with distractor only in the simple-detection task.

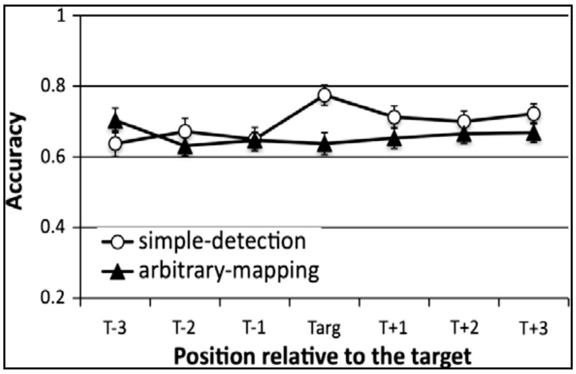

Figure 1.5. Accuracy of Memory for Image Identity as function of the Serial Position of the image during encoding in the *simple- detection* and in *arbitrary-mapping* tasks in Experiment 5 by Swallow and Jiang (2010). Bars represent standard errors.

Analysis of the reaction time (RT) for the target detection task revealed that participants were significantly slower in the arbitrary-mapping task than in the conjunction-search task (mean RT = 581 for the arbitrary-mapping task and 495 ms for the conjunction-search task). The authors concluded that the arbitrary-mapping task was more difficult than the conjunction-search task. Likely, the increased difficulty in the detection task with the arbitrary-mapping instructions led to greater competition for attentional resources when target appeared, cancelling the facilitative effects of target detection on scene encoding.

In conclusion, Swallow & Jiang (2010) interpreted their data in agreement with the *facilitation hypothesis*. Increasing attention to targets in one task facilitates or boosts performance in a second concurrent task: images presented with targets were better encoded than images presented with distractors. According to their interpretation, detecting an occasional target in a secondary task would induce a transient attentional response when the target appears. This attentive orientation response could lead to an increase in the available attentional resources, facilitating the processing and encoding of both the primary and secondary task stimuli in memory. To indicate this facilitation, they coined the term "*Attentional Boost Effect*" (ABE). In their experiments Swallow & Jiang (2010) showed that this advantage was observed across different types of detection tasks (simple oddball detection and feature-conjunction detection). However, it was eliminated when participants ignored the detection task and when responses were arbitrarily mapped to the targets in the detection task. The authors hypothesized that the ABE was a compromise between the attentional competition, due to the interference effect of the secondary task, and the memory facilitation, due to the transient increase in attention thanks to target detection (Swallow & Jiang, 2010). When the additional attentional requests needed to detect the target are relatively low (as in the simple detection task), the two effects produce a clear facilitation. As attentive requests for performing the secondary task increase (from the colour-shape conjunction task to the arbitrary-mapping task, in Exp. 4 and 5 by Swallow & Jiang, 2010*)*, interference goes beyond facilitation, eliminating the effect.

1.1.2.1. New paradigm of the Attentional Boost Effect

In the first paradigm of the Attentional Boost Effect (ABE), the performance obtained in a dived attention (DA) condition was compared to those obtained in a full attention (FA) condition (Swallow & Jiang, 2010, 2011, 2012). From this comparison, the authors deducted that the mechanism underlying the ABE was a trade-off between an attentional boost and an attentional competition. When the additional attentional requests needed to detect the target are relatively low, the two effects produced a clear facilitation (the ABE). As attentive requests for performing the secondary task increased, interference went beyond facilitation, eliminating the effect (see previous paragraph 1.1.2).

Swallow & Jiang (2014) modified the classical paradigm believing that the FA condition was not a correct baseline with which to compare the results obtained in the DA condition. Other cognitive factors, such as differences in cognitive load and task engagement, could influence the estimates of the memory when the squares (or the circles) were not process. Then, they created a new baseline in the contest of a dual-task encoding condition. Their aim was to highlight if the advantage of the target stimuli was based on a facilitatory mechanism due to the target detection (*enhancement hypothesis*) or on inhibitory mechanisms due to the distractor rejection (*inhibition hypothesis*), or a combination of them. To do this, Swallow & Jiang (2014) presented a series of faces flanked by two target squares (e.g., orange), two distractor squares (e.g., blue) or no squares – the latter condition representing the baseline (Figure 1.6). In this way, the processing of the baseline stimuli was not influenced either by the cognitive processes related to the elaboration of the targets nor by those linked to the refusal of distractors. The instructions were to study the faces and simultaneously press the spacebar when the target squares appeared on the screen (no action was required in response to the distractor squares). In the test phase, participants performed an old-new recognition task. The authors hypothesized that if the ABE reflected an enhancement induced by the target detection, then faces presented with targets should be remember better than faces presented with no-squares. In contrast, if inhibitory mechanisms underlying the ABE, rejecting distractors should inhibit the processing of the faces presented at the same time, then the distractor stimuli should be recognized more poorly than faces presented with no squares.

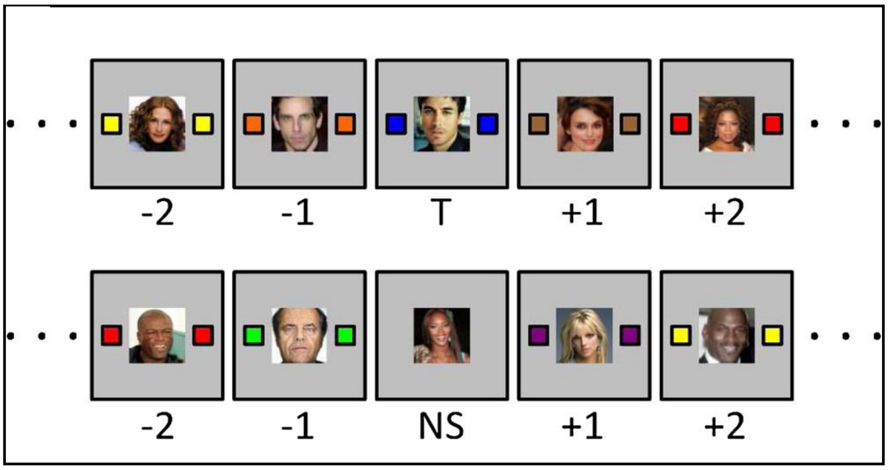

Figure 1.6. Representation of dual task encoding used in Experiment 1 by Swallow & Jiang (2014). Participants saw a long sequence of faces, flanked by two target squares of a specific colours (e.g., blu for the Target condition and other colours for the Distractor condition). Some faces were presented with no squares (Baseline condition). Participants had to memorize faces and at the same time pressing the space bar every time a target squares appeared.

Results (Figure 1.7) showed that the performance was significantly better for the faces encoded in the target condition than for the faces encoded in the distractor or no-square conditions, which did not differ between them.

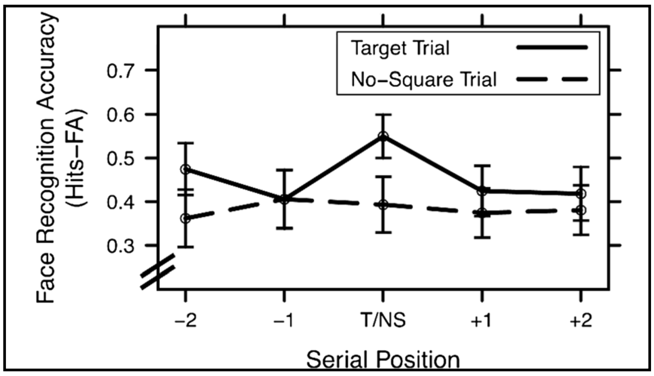

Figure 1.7. Proportions of Recognized Scenes depending on the Serial Position in relation to the target during encoding as function of Trial Type (T = target vs. NS = no-square) in Experiment 1 by Swallow and Jiang (2014).

In agreement with the *enhancement hypothesis*, these results demonstrated that the ABE represented a memory enhancement triggered by target detection rather than the action of inhibitory mechanism due to the distractor rejection. They did not exclude that some inhibitory process could occur, but they concluded that these processes did not have a primary role in the effect.

In the subsequent experiments, Swallow & Jiang (2014, Exp. 2 - 4) replicated this pattern of results using the same frequency for target, distractor and baseline stimuli (Exp. 2 and 3) and replacing the motor response to the targets with a covert counting task (Exp. 4).

In conclusion, as previously hypothesized (Swallow & Jiang, 2010), detecting a behaviourally relevant events (as targets) boosted memory for images presented at the same time in a dual-task condition.

1.1.3. The Attentional Boost Effect with verbal stimuli

Spataro, Mulligan, & Rossi-Arnaud (2013, Exp. 1) demonstrated for the first time the possibility to obtain an Attentional Boost Effect using verbal materials (words), reproducing the divided attention (DA) and full attention (FA) conditions of Swallow & Jiang (2010). In the DA condition, participants were instructed to study, and read aloud, each word presented. At the same time, they had to monitor the colour of a small circle immediately below the word and to press the spacebar whenever they saw an infrequent red circle among more frequent green circle. In the FA condition, the same procedure was used with the exception that participants were told to ignore the circles. After 5 minutes of distracting task, a four-choice recognition task was administered. Participants had to select the words studied during the encoding phase, choosing between four alternatives for every trial. The results in the DA condition showed a significant boost effect: the accuracy for words presented with targets was greater than that for words presented with distractors. On the contrary, no difference was found in the FA condition between targets and distractors words (Figure 1.8). As for the pictures (Swallow & Jiang, 2010), comparing the two attentional conditions, it is possible to observe the relativity of the effect: it enhanced memory for target words in the DA condition to the same level of the FA condition; in contrast, distractor words were recognized more accurately in the FA condition than in the DA condition, replicating the usual negative effect of a secondary task during encoding on explicit memory.

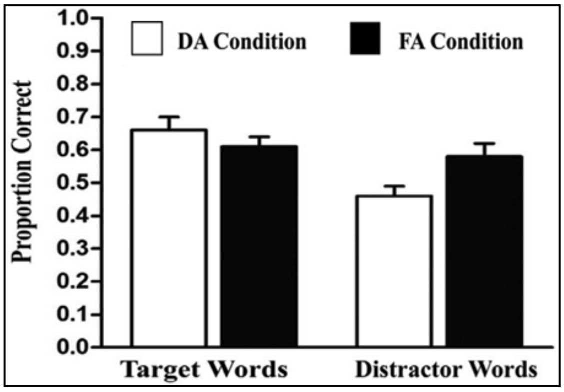

Figure 1.8. Proportions of Correct Recognition, as a function of Word Type (Target vs. Distractor) and Attentional Condition (DA vs. FA) in Experiment 1 by Spataro et al. (2013). Bars represent standard errors.

In conclusion, results of Spataro et al (2013) replicated the relative boost effect observed by Swallow & Jiang (2010) using verbal material, instead of pictures. The authors interpreted their results in agreement with the proposal that the Attentional Boost Effect (ABE) is mediated by enhanced perceptual encoding of visual stimuli that accompany targets. Furthermore, for the first time using a long-term paradigm, authors demonstrated that target and background stimuli not needed to overlap in space to produce a significant facilitation (see paragraph 1.1.4 of this chapter for previous results in a short-term visual memory paradigm).

Mulligan, Spataro, & Picklesimer (2014, Exp. 4 and 5) extended the ABE with verbal material to a free recall test. The procedure used was very similar to that used by Spataro et al. (2013), with the important exception that a free recall test was used instead of a recognition test. Their results (Exp. 4) showed a greater recall for words presented with targets than words presented with distractors (the ABE) only in the DA condition. No difference between target and distractor was found in the FA condition. Comparing the two attentional condition, the typical DA interference effect was found for words presented in distractor trials: recall of distractor words was lower in the DA than FA condition. Instead, recall of words from target trials was equal across attention conditions (Figure 1.9). However, the performance was near the floor in this study. Free recall is subject to substantial list length effects (then, shorter lists should produce higher proportional recall). The author replicated the experiment in the DA condition only, dividing the long study list into four lists, each of which was followed by the free recall test (Exp.5). With high recall levels, the results did not change: an ABE was evident in free recall (Figure 1.10).

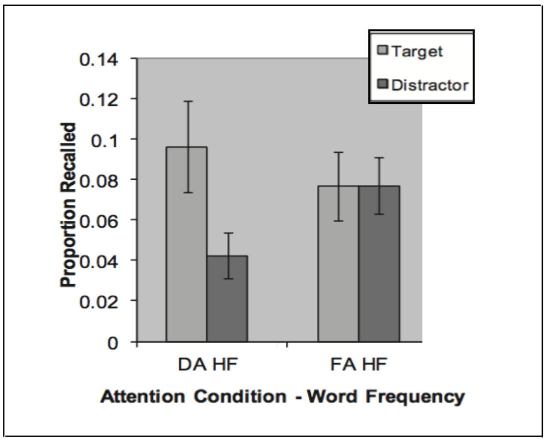

Figure 1.9. Mean Proportion Recalled of HF words as a function of Attention Condition (DA vs. FA) and Trial Type (Target vs. Distractor) in Experiment 4 by Mulligan et al. (2014). Bars represent standard errors.

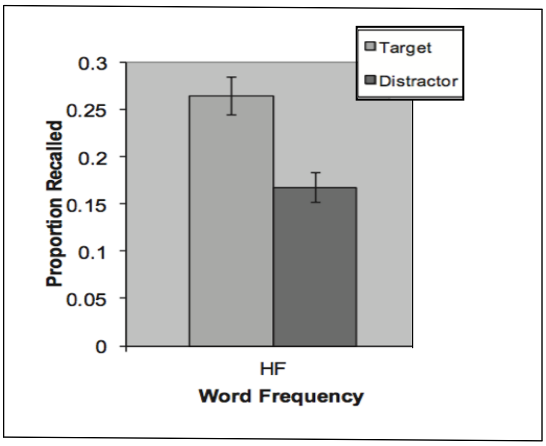

Figure 1.10. Mean Proportion Recalled of HF words as a function of Trial Type (Target vs. Distractor) in Experiment 5 by Mulligan et al. (2014). Bars represent standard errors.

In summary, Mulligan et al., (2014) found the ABE only in the DA condition, and it is confirmed to be a relative phenomenon, bringing the recall of target words in the DA condition up to the level of the FA condition. This was the same pattern found in recognition for both words (Spataro et al., 2013) and pictures (Swallow & Jiang, 2010).

1.1.3.1. The Attentional Boost Effect occurs in an early phase of the encoding

Traditionally, in word encoding two phases are distinguished, an early-phase and a late-phase. The early-phase of memory encoding involves initial stimulus perception and comprehension, while the late-phase involves controlled and elaborative rehearsal (i.e., conceptual elaboration, mental imagery, and so forth) (Atkinson & Shiffrin, 1968; Craik & Lockhart, 1972; Criss & Malmberg, 2008).

Mulligan & Spataro (2015) hypothesized that the positive effect of the targets detection took place during an early-phase of the memory encoding, while previous studies indicated that the negative effects of distraction on memory encoding impact in the later phase (a common view; i.e., Craik et al., 1996; Mulligan, 2008). To verify this hypothesis, they assessed if increasing study times influenced the ABE in recognition memory (Mulligan & Spataro, 2015, Exp. 1). If the ABE occurred during an early-phase, should be robust with relatively short study times and should not increase in size with further increases in study time. Indeed, for long study times, the role of late-phase encoding increases such that the early-phase advantage for the DA-target condition will no longer offset the late-phase negative effects. The author divided participants between three time conditions, 700, 1500 or 4000ms. In the divided attention (DA) condition, participants were told to read aloud and try to remember each word. Simultaneously, they had to monitor the colour (red or green) of a small circle immediately below the word and to press the space bar whenever the red circle appeared. On each trial, one word and one circle (red or green) appeared simultaneously at the centre of the screen for 100 ms. After only the word remained visible for an additional period of time, depending on the time condition (either 500; 1,300; or 3,800 ms). After an interval time, that was variable to equate the average retention interval across study times, an old-new recognition test was administered. The authors performed also an experiment in a full attention (FA) condition with the same procedure, except for the instructions: participants had to memorize each words and ignored the squares. Results in the DA condition indicated greater accuracy for target words than for distractor words (the ABE) in all three time conditions. Furthermore, the ABE did not increase in size with increasing study time. On the contrary, the ABE was numerically largest in the 700-ms condition and smallest in the 4,000-ms condition. When the 4.000 ms condition was examined by itself, the ABE was not significant (Figure 1.11). Comparing the results with those obtained from the FA condition, the DA-target condition was equivalent to FA condition at the shorter study time (700 ms) but was significantly worse than the FA condition at the long study time (4,000 ms). Then, the equality of the DA-target and FA conditions usually observed in the explicit ABE paradigm was eliminated by a sufficiently long study duration.

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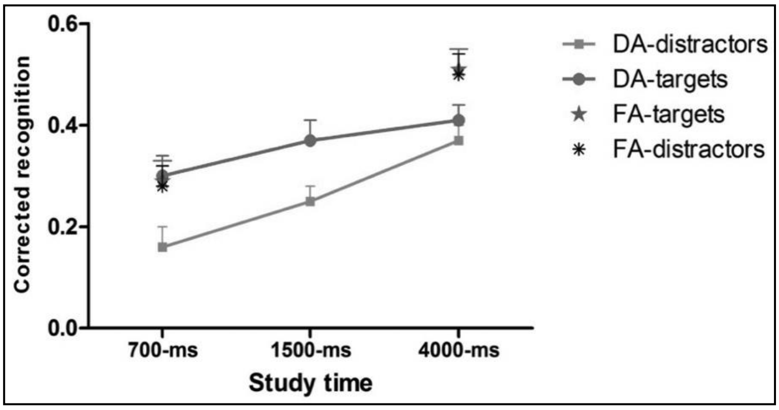

Figure 1.11. Mean Corrected Hits as a function of Study Time (700 vs. 1500 vs. 4000 ms), Attention Condition (DA FA), and Trial Type (Target vs. Distractor) in Experiment 1 by Mulligan & Spataro (2015). Bars represented standard errors.

The results were consistent with the hypothesis that the ABE was mediated by an early-phase memory encoding and not by later stage controlled rehearsal processes, which would lead to increase ABE with study time. For long study times, the negative influence on the late-phase encoding processes due to the DA condition exceeded the enhancement in early-phase encoding in the DA-target condition, producing a net negative effect on memory even for the DA-target condition.

1.1.3.2. Absolute Attentional Boost Effect

The first studies about the Attentional Boost Effect (ABE) showed the relative nature of this phenomenon (Swallow & Jiang, 2010; Spataro et al., 2013; Mulligan et al., 2014). For the stimuli (pictures or words) accompanied by the distractor squares (or circles), the divided attention (DA) condition produced worse recognition memory then did the full attention (FA) condition, the typical DA interference effect on memory encoding. For stimuli accompanied by target, memory was equal in the two attentional conditions, which indicated the elimination of the negative DA effect.

Spataro et al. (2013) demonstrated, for the first time, the possibilities to obtain an absolute ABE using implicit tasks in the test phase. They showed that detecting an infrequent target in a dual-task paradigm improved memory encoding for concurrently presented word above and beyond the performance reached in the full-attention condition. As in the paradigm of the ABE with words presented above (Spataro et al., 2013, Exp. 1 – see paragraph 1.1.3 for the procedure), they contrasted a divided attention (DA) condition with a full attention (FA) condition. In the DA condition, participants read aloud a series of words and concurrently monitored the colour (red or green) of a small circle placed below each word. In the FA condition, participants simply read the words but ignored the circles. But unlike in the previous studies where was used an explicit recognition task, in the test phase they used two different perceptual implicit tasks. In general, DA during encoding produces much weaker effects on implicit memory than explicit memory (Mulligan, Duke, & Cooper, 2007; Parkin, Reid, & Russo, 1990; Mulligan, 2003; Mulligan & Brown, 2003; Spataro, Cestari, & Rossi-Arnaud, 2011). For this reason, the authors hypothesized that for words encoded with distractor circles, the FA and DA conditions should produce comparable amounts of priming. In contrast, for words encoded with target circles, priming should be significantly greater in the DA condition than in the FA condition, because the facilitating effect due to the detection of the target circles should overcome any small attentional interference produced by the dual task.

In their experiments, Spataro and colleagues (2013, Exp. 2 and 3) examined the ABE in a lexical decision task (LDT) and in a word-fragment completion (WFC) task respectively, two perceptual implicit tests characterized by a strong resilience to the negative consequences of DA (Mulligan & Peterson, 2008; Newell, Cavenett, & Andrews, 2008; Spataro, Mulligan, & Rossi-Arnaud, 2011; Roediger & McDermott, 1993; Mulligan & Hartman, 1996; Spataro, Mulligan, & Rossi-Arnaud, 2010). In the LDT, participants were presented with 45 critical words (30 studied in the encoding phase and 15 unstudied) and 45 legal pronounceable non-words. The instructions were to decide if each item was a valid Italian word by pressing either *S* (*si* for yes) for word or *N (no)* for non-word. The participants had to be as fast and accurate as possible, and no mention was made about the relationship with the study phase. In the WFC task, participants were presented with a total of 70 fragments corresponding to 45 critical words (30 studied and 15 non studied) plus 25 filler words (new words not presented in the encoding phase). Participants tried to complete the fragments with the first word that came to mind. It is important to highlight that the encoding was incidental, because participants were required to read aloud all the words but were not told to remember them for a later memory task. Besides, using implicit tests, the ABE was no longer linked to the difference between target and distractor conditions in the recognition accuracy. Instead, it was based on the difference in priming between the stimuli presented with the target and those presented with the distractor. In the LDT, priming scores were computed as the difference between RTs for unstudied and studied words; in the WFC task, priming was computed as the difference between the proportion of correct completions for studied and unstudied words. The results, in both experiments (Figure 1.12 and 1.13), showed an Attentional Boost Effect (ABE) in the DA condition: priming scores were greater for target words (encoded with red circles) than for distractor words (encoded with green circles). No ABE was found in the FA condition. A very important point is that the ABE found was absolute. Indeed, priming scores for target words were significantly greater in the DA condition than in the FA condition. Contrary to experiments with explicit tests, no difference between the two conditions was obtained for distractor word, confirming that a dual task with infrequent response rates did not disrupt implicit memory (Mulligan et al., 2007).

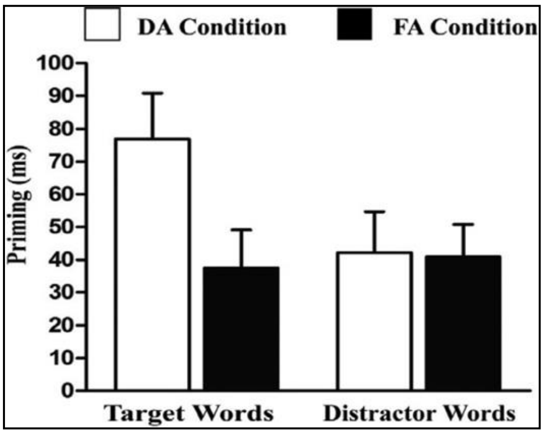

Figure 1.12. Priming Scores in the lexical decision task (LDT), as a function of Word Type (Target vs. Distractor) and Attentional Condition (DA vs. FA) in Experiment 2 by Sapatro et al. (2013). Bars represent standard errors.

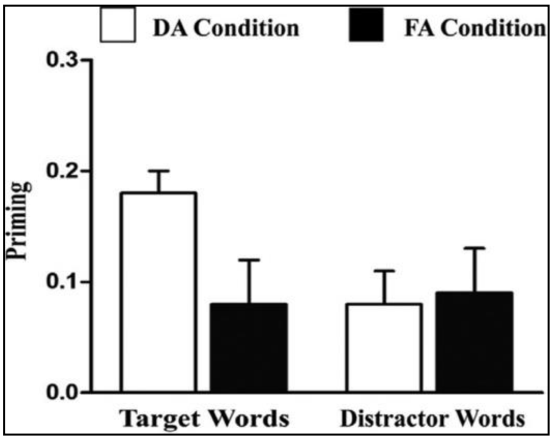

Figure 1.13. Priming Scores in the word fragment completion (WFC) task, as a function of Word Type (Target vs. Distractor) and Attentional Condition (DA vs. FA) in Experiment 3 by Spataro et al. (2013). Bars represent standard errors.

The results of these two experiments (Spataro et al., 2013, Exp. 2 and 3) showed that an absolute Attentional Boost Effect was observed in the LDT and WFC test. According to Swallow and Jiang (2010), this happened because the attentional orienting response following target detection facilitates the perceptual encoding of the concurrent word, overcoming any negligible interference caused by the dual task.

Mulligan & Spataro (2015, Exp. 2) showed the possibility to obtain an absolute ABE also with an explicit task in the test phase. As explained above (paragraph 1.1.3.1), the early-phase of memory encoding involves initial stimulus perception and comprehension, while the late-phase involves controlled and elaborative rehearsal (Atkinson & Shiffrin, 1968; Craik & Lockhart, 1972; Criss & Malmberg, 2008). Mulligan & Spataro (2015, Exp. 1) demonstrated that ABE occurred during an early-phase, because it was robust with relatively short study times and not increased in size with further increases in study time. For long study times, the role of late-phase encoding increased such that the early-phase advantage for the DA-target condition did not offset the late-phase negative effects. The results was that the negative influence on the late-phase encoding processes due to the DA condition exceeded the enhancement in early-phase encoding in the DA-target condition, producing a net negative effect on memory even for the DA-target condition. Then, in a later experiment, Mulligan & Spataro (2015, Exp. 2) presented stimuli with a very short study duration (400 ms), hypothesizing that the brief study times should produce a net positive effect for the DA-target condition. This was because the contribution of late-phase elaborative rehearsal should be severely curtailed (and so the negative effect of DA), whereas the early-phase enhancement to encoding in the DA-target condition should still accrue. Results (Figure 1.14) indicated a quite robust ABE also with study time as brief as 400 ms. More importantly, the DA-target condition produced significantly better memory compared to the FA condition.

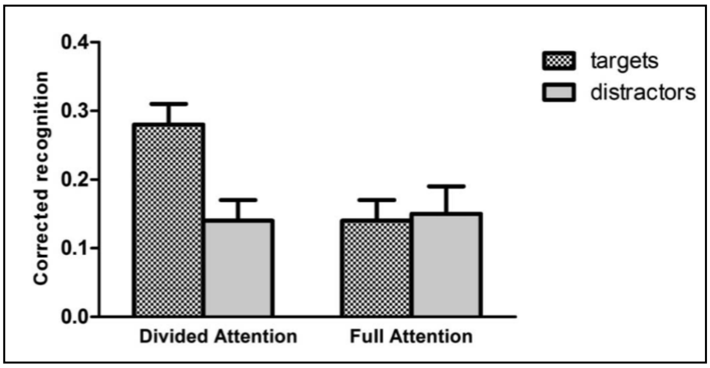

Figure 1.14. Mean Corrected Hits as a function of Attention Condition (DA vs. FA) and Trial Type (Target vs. Distractor) in Experiment 2 by Mulligan & Spataro (2015). Bars represent standard errors.

With the elimination of the late-phase disadvantage, the facilitation for the DA-target condition was visible in a net positive effect on recognition memory relative to the FA condition. At the same time, the DA-distractor condition could reach the level of the FA accuracy.

It was important to highlight that Mulligan & Spataro (2015) obtained, for the first time, using brief study time, an absolute ABE in an explicit memory test. Therefore, the role of late-stage encoding could be diminished at retrieval (by measuring memory with a perceptual priming task) or at encoding (by reducing study time), and in so doing, a net positive effect of divided attention in the target condition could be observed.

1.1.3.3. Limits of the verbal Attentional Boost Effect

Studies with verbal material showed an important limit of the Attentional Boost Effect (ABE). In particularly, these studies showed that the ABE did not occur with specific categories of words, namely low-frequency and orthographic distinctive words.

In their experiments, Mulligan, Spataro, & Picklesimer (2014, Exp. 1) used high-frequency (HF) and low-frequency (LF) words to investigate the boost effect. In the DA condition, participants had to read aloud and try to remember a series of words. At the same time, they had to press a key every time a red circle appeared under the word, and ignoring the more frequent green circle. The FA condition was identical except that participants were told to ignore the circles and focus only on remembering the words. Word frequency (HF and LF words) was counterbalanced over trial type (target and distractor). In the test phase, a recognition test, visual or auditory, was administered. The analysis (Figure 1.15) showed that, as expected, memory was better for LF than HF words, replicating the classical word frequency effect in recognition memory. The results on the HF words showed the classical ABE in the DA condition. Comparing this result with those obtained in the FA condition, it could be see the usual relativity of the boost effect. Interestingly, the ABE was only marginally significant with LF words, and changing test modality had no effect.

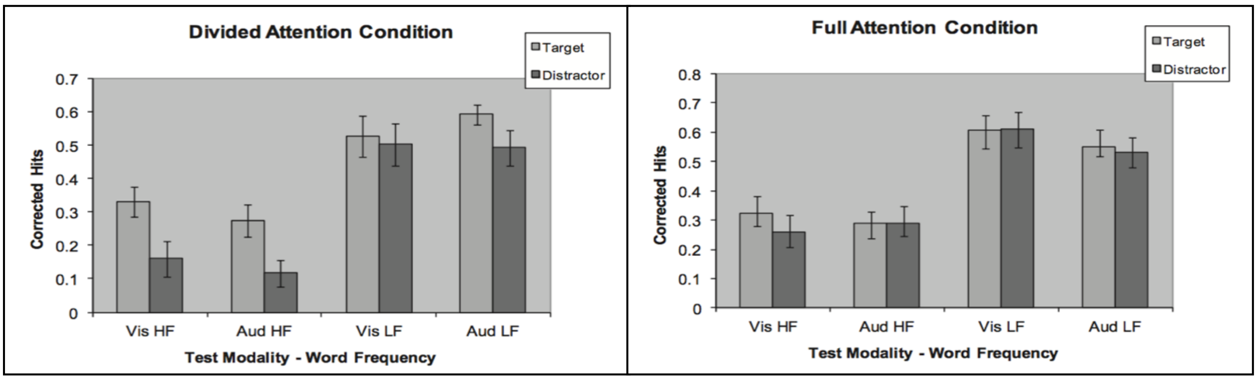

Figure 1.15. Mean Corrected Hits as a function of Attention condition (DA vs. FA), Test modality (Aud = auditory; Vis = visual), Word frequency (HF = high frequency; LF = low frequency), and Trial type (Target vs. Distractor) in the Experiment 1 by Mulligan, Spataro, & Picklesimer (2014). Bars represented standard errors.

The authors (Mulligan, Spataro, & Picklesimer, 2014, Exp. 2) replicated these results in a new experiment changing, this time, the modality in the encoding phase between participants. Again, the ABE was found in the DA condition and was not influenced by the modality match. The effect was limited to the HF words; no ABE was found for LF words. Similar results were obtained using a free recall test instead of the recognition task (Mulligan, Spataro, & Picklesimer, 2014, Exp.

5; see paragraph 1.1.3). Indeed, the ABE was larger for HF than LF words, consistent with the results found with the recognition test.

The authors interpreted their results suggesting that the processes underlying the memory advantage for the LF words were redundant with the facilitation brought by the ABE. In agreement with the *early-phase-elevated-attention hypothesis* (Criss & Malmberg, 2008; Malmberg & Nelson, 2003), LF words, compared to HF words, attract more attention during the early-phase of encoding, a relatively automatic processing stage that comprised the stimulus perception and comprehension. Because of the unusual properties of the LF words, a larger amount of attention resources would be devoted to their elaboration in this early processing phase. Consequently, a greater number of features of these words and the circumstances of their occurrence were better remembered (Malmberg & Nelson, 2003).

In conclusion, the ABE enhances memory for HF words but not for LF words because the latter are already subject to heightened attention. The lack of an ABE with LF words implies that the encoding advantage in the target condition may be largely redundant with the processing that typically happens with LF words. Indeed, according to Mulligan et al. (2014 – about this interpretation, see paragraph 1.1.3.1), the differential encoding accruing to target words in the ABE paradigm would also arise early at encoding, rendering this attentional manipulation largely redundant with the increased processing naturally occurring for LF words.

Spataro, Mulligan & Rossi-Arnaud (2015) extended previous results and investigated the interaction between the Attentional Boost Effect (ABE) and the orthographic distinctiveness effect (ODE). The ODE refers to the finding that words with rare letter combinations (i.e., unusual visual patterns) are remembered better than words with common letter combinations (Hunt & Elliot, 1980). The context of similarity between items allow to compute the differences between them (Hunt & Elliot, 1980; Smith & Hunt, 2000). Then, in the context of mixed study lists, the encoding of orthographically distinctive words attracts more attentional resources, compared to the encoding of orthographically common words (Hunt & Elliot, 1980).

Spataro et al. (2015) tested whether target detection in the DA condition of the ABE paradigm could enhance memory of co-occurring low-frequency (LF) words with common or distinctive orthographic properties. They hypothesized that if LF words are encoded in the context of other items having similar frequency but higher orthographic distinctiveness, then more attention should be devoted to the encoding of low-frequency orthographically distinctive (LF-OD) words. As results, the low-frequency orthographically common (LF-OC) words should be processed less accurately. Coupled with previous evidence indicating that the ABE produces little benefits to the encoding of stimuli which are already subject to heightened attention during the study phase (Mulligan et al., 2014), this hypothesis led to expect that a significant boost-related facilitation should occur for LF-OC words but not for LF-OD words. Spataro and colleagues (2015) presented randomly a long series of LF words, half was LF-OD words and the other half was LF-OC words. In the DA condition, participants were told to read aloud and study each word while simultaneously pressing a key of the computer whenever they detected a red square. In the FA condition, participants were told to ignore the squares and focus only on the words. The results (Figure 1.16) showed that recognition memory was significantly better for LF-OD than for LF-OC words and better in the FA than in the DA condition. Interestingly for our discussion, in the DA condition the ABE was significant for LF-OC words (recognition being better for words encoded with targets than for words encoded with distractors), whereas there was no ABE for LF-OD words. Finally, comparing the two attentional conditions, the interfering effect of DA was significant for LF-OC words encoded with distractors and for LF-OD words encoded with both targets and distractors.

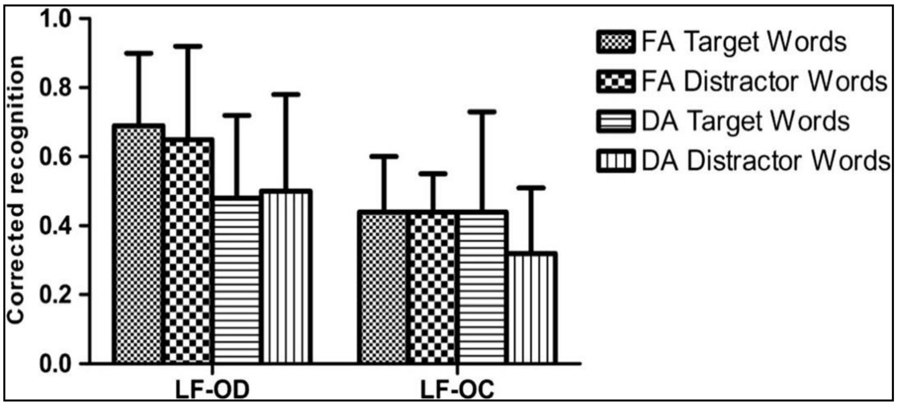

Figure 1.16. Mean Corrected recognition Scores, as a function of Item Type (LF-OD vs. LF-OC words), Trial Type (Target vs. Distractor trials) and Attention Condition (DA vs. FA) by Spataro et al. (2015). Bars represent standard errors.

Spataro et al. (2015) showed that ABE did not enhance the recognition of LF-OD words when they were encoded in the context of other blocks containing LF-OC words. They interpreted their results in according to Hunt and Elliot (1980): in the context of mixed study lists, the visual irregularity of LF-OD words would induce participants to perform a more detailed analysis of their orthographic properties, which in turn offsets any additional processing advantage induced by the ABE.

1.1.4. The Attentional Boost Effect in the short-term memory

Data presented until now about the Attentional Boost Effect (ABE) with visual and verbal materials indicated that detecting a target influences the way other, unrelated information was processed. This facilitatory effect of detecting a target on concurrent image processing could also be observed in short-memory task (Lin et al, 2010; Makovski, Swallow & Jiang, 2011). The visual short-term memory (VSTM) is a system extremely limited in capacity with estimates ranging from one to four items (Cowan, 2001; Jonides et al., 2008; Olsson & Poom, 2005). Furthermore, attention is critical for encoding and maintaining items in VSTM (Makovski & Jiang, 2007; Makovski, Shim, & Jiang, 2006; Makovski, Sussman, & Jiang, 2008).

Makovski et al., (2011) wanted to verify if the facilitatory effect due to the detection of targets occurred when the memory-encoding task tapped into a system with severe capacity limitations. In particular, they tested if increasing attention to a target letter influenced VSTM for an unrelated colour array. On each trial participants were shown a circular array of 3 or 5 colours (memory display) and were asked to remember the colours (Figure 1.17). After a short retention interval, a second colour array of 3 or 5 colours appeared (probe display). Participants had to indicate whether the display was the same or different than the memory display (*change detection task*). At the same time, participants performed a target detection task on a letter presented at fixation. The central letter was presented concurrently with the memory array, and the participants had to press the spacebar every time the target letter appeared (*letter detection task*).

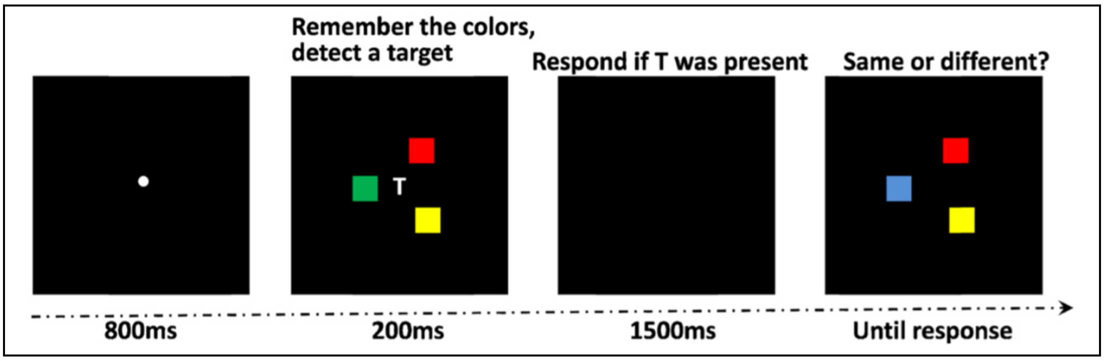

Figure 1.17. Schematic illustration of the trial sequence and task requirements in Experiment 1 by Makovski et al. (2011). Items are not drawn to scale.

Results (Exp. 1a, Figure 1.18) showed a better performance when the memory load was 3 rather than 5, revealing limited capacity in VSTM. More important for our discussion, the memory for colours presented with target letters was higher than for colours presented with distractor letters, replicating the Attentional Boost Effect (ABE). In a second experiment, Makovski and colleagues (2011, Exp. 1b) obtained the same results using the same procedure but with target and distractors of the same frequency (Figure 1.18).

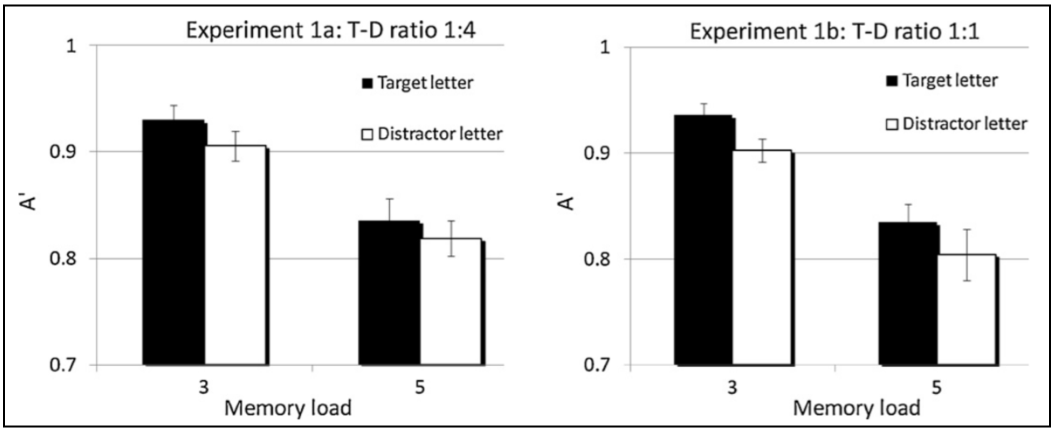

Figure 1.18. Change detection performance (in A′) as a function of Set Size (3 vs. 5 colours) and Trial Type (Target vs. Distractor) in Experiment 1a (left) and 1b (right) by Makovski et al. (2011). Bars represent standard errors.

These data were consistent with the hypothesis that the Attentional Boost Effect resulted from a transient increase in perceptual processing of all task-relevant information in response to the detection of a target (Swallow & Jiang, 2010). Moreover, having found the effect even when targets and distractors had the same frequency in the letter detection task suggested that the ABE was not due to distinctiveness of the target events (see paragraph 1.1.5.2 for the same results in the long-term paradigm of the ABE).

In conclusion, the benefit of target-detection was not restricted to long-term memory of scenes, faces and words (Swallow & Jiang, 2010, 2011). It also occurred in short-term memory tasks, and for stimuli that were semantically impoverished. Moreover, the spatial overlap between the two tasks seemed not to be necessary, because the ABE was present in a task where the target was spatially separated from the VSTM colour arrays.

1.1.5. The Attentional Boost Effect: what it is not.

Previous experiments (Swallow & Jiang 2010; Spataro et al., 2013) suggested that increasing attention to the detection task when a target appeared boosted performance in the encoding task. In the detection task, the participants had to press a key every time an infrequent target appeared in the centre of the screen. No action was requested for the more frequent distractors. A first distinction between target and distractor was that target required to generate a response. For this reason, Swallow & Jiang (2010) focused on the behavioural relevance of targets in their discussion of the Attentional Boost effect (ABE). They suggested that detecting goal-relevant events may trigger an attentional orienting response that regulates the processing and encoding of perceptual information. However, there are other factor that distinguished targets from distractor that could play a central role in the effect.

1.1.5.1. Perceptual saliency of the target

The target used in the attentional boost manipulation were usually perceptually salient. For example, the white square in Swallow & Jiang (2010) was brighter than black square. If the Attentional Boost Effect (ABE) was driven by the perceptual saliency of the target square, then the effect should be still observed when the white square was not task relevant. Alternatively, if the boost was triggered by a change in the attentional demands of the detection task, as hypothesized by Swallow & Jiang (2010), then it should be eliminated if participants did not pay attention to the stimuli. Swallow & Jiang (2010, Exp. 3) performed an experiment where the participants were instructed to memorize the pictures and ignored the squares, recreating a full attention (FA) condition (see paragraph 1.1.2 for the procedure). In this paradigm, no memory advantage was observed for scenes that were presented at the same time as a white square. The absence of the ABE in this condition indicated that the effect was not due to the perceptual distinctiveness of the infrequent target squares, but rather that these squares must be processed as targets (e.g., responded to) to produce the ABE (see also Makovski, Jiang, & Swallow, 2013).

1.1.5.2. Frequency of the target

Another and more important difference between targets and distractors in the studies illustrated so far was the fact that targets were less common than distractors. The low frequency of targets made possible that processes associated with detecting rare or distinctive events might contribute to the memory enhancement observed in the Attentional Boost Effect (ABE) (Swallow & Jiang, 2012). It has long been known that rare, new and distinctive events, even those that are not perceptively distinctive, affect long-term encoding and memory (Fabiani & Donchin, 1995; Geraci & Rajaram, 2004). Swallow & Jiang (2012) performed a series of experiments to investigate if the ABE was modulated by the frequency of targets.

In their first experiment, they used the usual paradigm of the ABE. The participants had to encode faces into memory and monitor coloured squares to detect targets. The frequency with which targets and distractors were presented ranged between blocks: in the half of the blocks, the target was a rare event (it had a lesser frequency than that of the distractors), in the other half the targets had the same frequency as the distractors (Figure 1.19). If the boost effect was due to memory processes triggered by rare events, then it should be absent when targets were frequent as distractors. Conversely, if the effect was triggered by detection of targets that signalled the need to give a response (regardless of their frequency), then it should be similar when targets and distractors had the same frequency and when they had not.

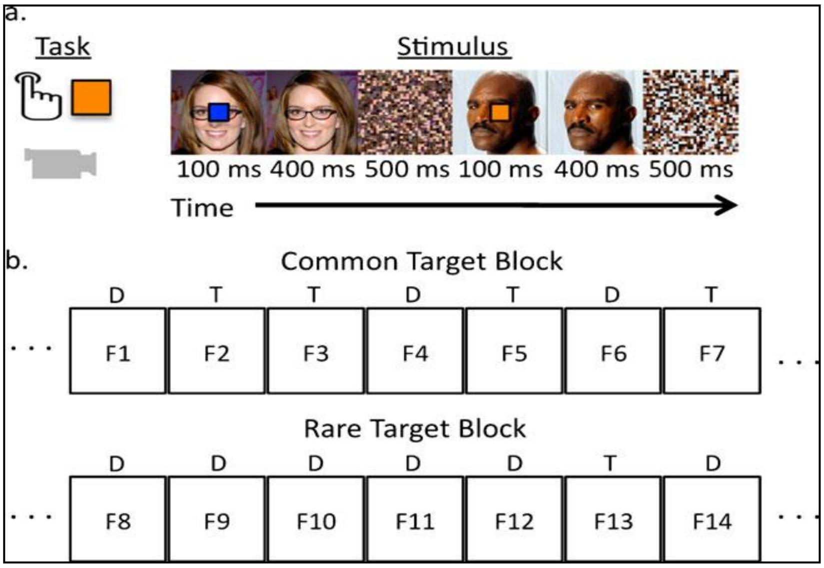

Figure 1.19. Representation of dual task encoding used in Experiment 1 by Swallow & Jiang (2012) (**a.**) Participants viewed a series of faces that remained on the screen for 400 ms and then they were masked for 100 ms. In te firs 100 ms of the trial, the face was presented with with a square (blue orange). Participants encoded faces for a later memory test and had to press a key as fast as possible every time appeared the square. (**b.**) the target frequency (T) compared to the distractor frequency (D) varied between blocks: in the half of the blocks, the target was a rare event (ratio 1:6), in the other half the targets had the same frequency as the distractors (ratio 1:1).

After completing the dual-task encoding phase of the experiment, participants performed an old-new recognition test on the faces. On each trial, a single face was presented at the centre of the screen, and the participants pressed one of two keys to report whether they had seen the face in the encoding phase. The results (Figure 1.20) showed that the faces presented at the same time as the target were better recognized than those presented with the distractors both when the target was frequent and when it was not.

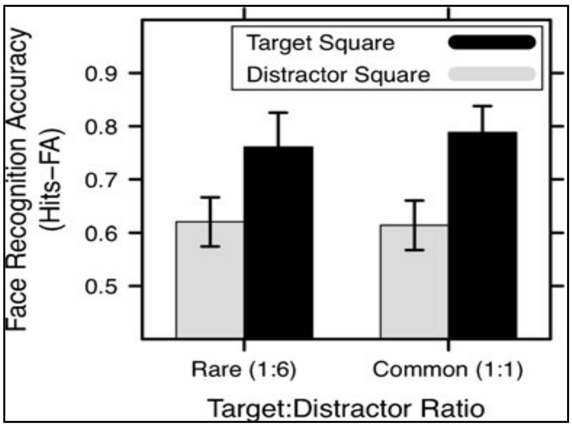

Figure 1.20. Proportions of Corrected Scores for images presented during the dual-task encoding phase as function of Target: Distractor Ratio (Common

vs. Rare Target) and Trial Type (Target vs. Distractor) in Experiment 1 by Swallow & Jiang (2012). Bars represent standard errors.

As only in half of the blocks targets and distractors had the same frequency, the total frequency of targets remained lower than that of the distractors. The authors then replicated their results by equalizing the target frequency and distractors in all blocks (Swallow & Jiang, 2012, Exp. 2): faces presented with target were better recognized compare to faces presented with distractors. These data indicate that the relative frequency of the target did not affect the boost effect.

In their third experiment, Swallow & Jiang (2012, Exp. 3) introduced a third type of detection stimulus. The procedure was the same of used in the second experiment: participants monitored a stream a coloured squares and pressed a button whenever the square was a target colour. Target and distractor had the same frequency. However, there were two types of distractors: one that was common, appearing on 40% of the trials (*common-distractor condition*), and another that was rare, appearing on 10% of trials (*rare-distractor condition*). If rare or distinctive stimuli enhance the processing of concurrently presented information, then images presented at the same time as rare distractors should be recognized better than images presented at the same time as common distractors. Results showed that the ABE was present independently of the distractors condition (Figure 1.21): images of objects that were presented at the same time as a target coloured square were recognized better than images in the two distractor conditions. Furthermore, the images in the rare-distractor condition were, not better, but more poorly recognized than images in the common-distractor condition.

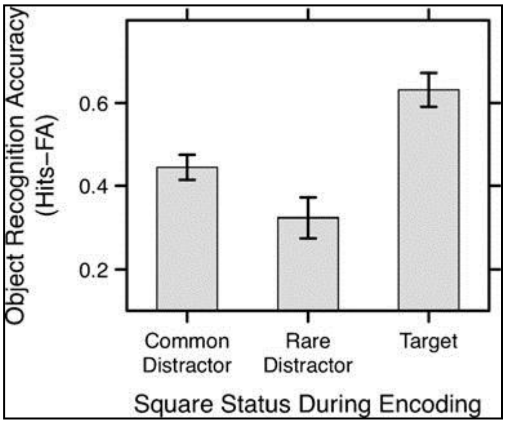

Figure 1.21. Proportions of Corrected Scores for images presented during the dual-task encoding phase as function of Square Status (Common Distractor vs. Rare Distractor vs. Target) in Experiment 3 by Swallow & Jiang (2012). Bars represent standard errors.

These results, all together, demonstrated that the distinctiveness of the stimuli in the detection task is not enough to improve memory for the images presented at the same time.

1.1.5.3. Type of response to the target

Swallow & Jiang (2012, Exp. 2) investigated if the effects of processing goal-relevant events were restricted to events that require a manual response. The author varied the type of response that participants made to target events. On half of the blocks, participants pressed a key every time a specific target coloured square occurred (*button press condition*). On the other half of the blocks, participants counted the number of times a target square with another specific colour appeared (*count condition*). For the counting task, participants were instructed to avoid making verbal or motor responses to the targets. If the Attentional Boost Effect (ABE) depended on the execution of a manual answer, then it should be observed only in those blocks where this response was required and not in others. Conversely, if the effect reflected processes triggered by responses to goal relevant events, images presented with targets should be better recognized than those presented with the distractors, independently of the response mode. The results (Figure 1.22) supported this last hypothesis: the images presented with targets were better recognized than those presented with distractors, regardless of the type of response.

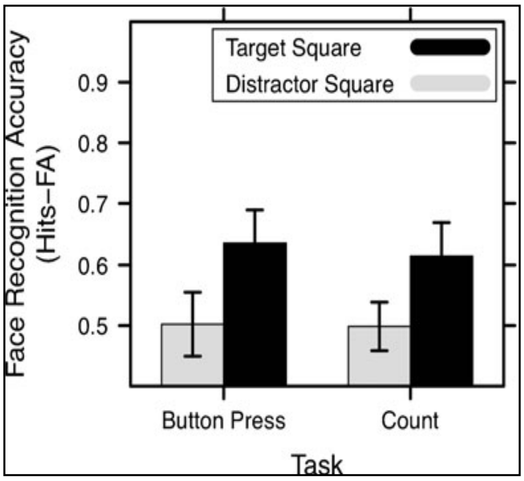

Figure 1.22. Proportions of Corrected Scores for images presented during the dual-task encoding phase as function of Task Condition (Button press vs. Count tasks) in Experiment 2 by Swallow & Jiang (2012). Bars represent standard errors.

Although it is difficult to rule out the possibility that participants never produced any sort of motor response to the targets, such as sub-vocalization of their internal counts, these data generalized the Attentional Boost Effect to a task for which such responses are not necessary and are less likely to be performed.

1.1.5.4. Sensorial modality

Early studies on the ABE showed its occurrence irrespective of the mode of detection. Swallow & Jiang (2010, Exp. 2) replicated their first experiment using auditory stimuli in the detection task. They performed an experiment with the same procedure usually described (see paragraph 1.1.2 for an example of the procedure), but this time in the encoding phase the participants had to perform an auditory, not visual, detection task. Participants were asked to press a key each time they heard the target tone (a low tone of 200 Hz) and did not give any response when they heard the destroying tone (a high 400 Hz tone). Again, the results (Figure 1.23) showed that the recognition was better for the images presented with the target tone compared to the images presented with the distractor tone.

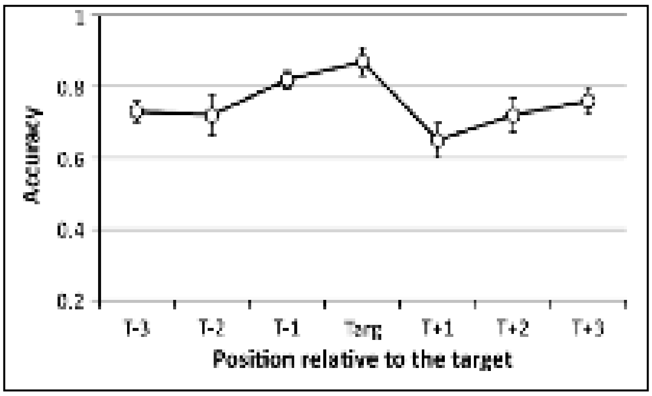

Figure 1.23. Scene Identity Memory Accuracy as a function of the scene's Serial Position during encoding in Experiment 2 by Swallow & Jiang (2010). Bars represent standard errors.

This result indicated that the detection of auditory target could facilitate pictures encoding. The advantage for images encoded with auditory target remained even when targets and distractors had the same frequency (Swallow & Jiang, 2012, Exp. 4).

Mulligan, Spataro, & Picklesimer (2014) extended previous results changing the modality of the memory task between encoding and test phases, and using always a visual detection task. In their first experiment (Mulligan et al., 2014, Exp. 1), they used a visual encoding phase with verbal stimuli. Participant saw a series of word with a circle (red or green) below, in the centre of the screen. They have to read aloud and try to remember all the words, and, at the same time, press the spacebar whenever they saw an infrequent red circle (target) among more frequent green circles (distractor). After 5 minutes of interval, the authors administered a recognition task, that could be visual or auditory. Half of the participant was assigned to the *visual test condition*, the other half to the *auditory test condition*. In the visual test, participants saw the test word in the centre of the screen and pressed the "O" key for old and the "N" key for new. Auditory test was identical except that the participants heard the word over headphones. The results (Figure 1.24) indicated a robust Attentional Boost effect (ABE), of a comparable size, in both test modalities.

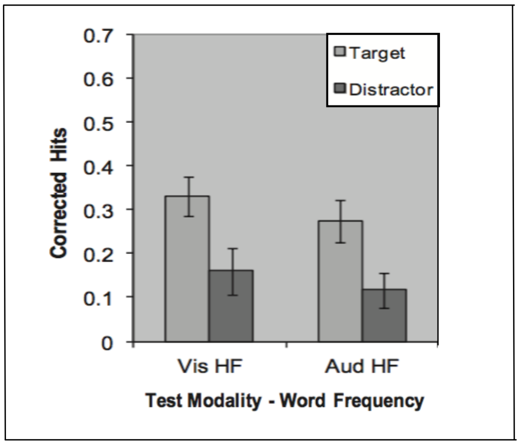

Figure 1.24. Mean Corrected Hits as a function of Test Modality (Aud = auditory vs. Vis = visual) and Trial Type (Target vs. Distractor) in the Experiment 1 by Mulligan, Spataro, & Picklesimer (2014). Bars represent standard errors.

In a second experiment, Mulligan, Spataro, & Picklesimer (2014, Exp. 2) changed also the modality of the memory task in the encoding phase. The procedure was the same of their first experiment, but the studied words were presented aurally instead of visual. The detection task remained visual and the recognition task was either auditory or visual, as in the first experiment. The results showed again a boost effect in both test modalities: the words from target trials were better recognized than words from distractor trials (Figure 1.25). Consistent with Experiment 1 (Mulligan, Spataro, & Picklesimer, 2014), the ABE was the same size for both a matching test modality (auditory recognition) and a mismatching test modality (visual recognition).

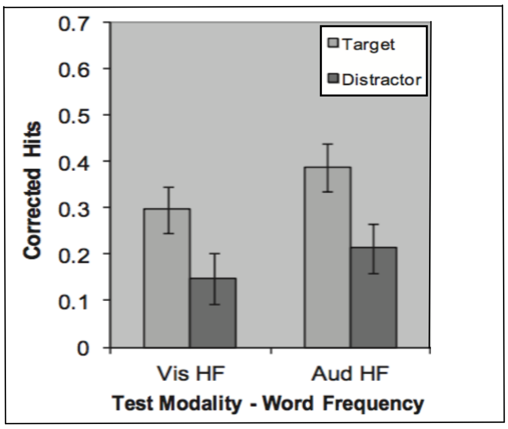

Figure 1.25. Mean Corrected Hits as a function of Test Modality (Aud = auditory vs. Vis = visual) and Trial Type (Target vs. Distractor) in the Experiment 2 by Mulligan, Spataro, & Picklesimer (2014). Bars represent standard errors.

In conclusion, the Attentional Boost Effect could be found independently from the modality of the study stimuli in the encoding and in the test phase (Mulligan, Spataro, & Picklesimer, 2014) or that of the detection task (Swallow & Jiang, 2010; 2012).

1.1.6. Possible explanatory hypotheses

In the Attentional Boost Effect (ABE), the processing of unrelated background stimuli was enhanced when a target was detected in an unrelated task. Swallow & Jiang (2010) hypothesized that the detection of the target triggered a transient attentional increment, thank to which the perceptual processing of the stimuli contemporary to the target was enhanced. But it was possible that this phenomenon reflected the operations of other well-studied mechanisms (Swallow & Jiang, 2011). In order to exclude these possibilities, the authors conducted specific experiments.

1.1.6.1. Attentional cuing hypotheses

The first possibility investigated by Swallow & Jiang (2011) was a simple attentional cuing effect. In target detection tasks, behaviourally relevant events elicited an attentional orienting response, which enhanced not only the target event, but also the processing of stimuli that were presented concurrently with the target (Swallow & Jiang, 2010). In the classical experiments demonstrating the Attentional Boost Effect (ABE), the target and the image onset at the same time but the image remained on the screen for several hundred milliseconds after the target. It was therefore possible that the target might act as a cue to orient attention, with visuospatial attention spreading from it to the background image that was presented in the same location as the target. Perceptual enhancement as a consequence of orienting attention to a target peaks approximately 100–200 ms after the target appears (Egeth & Yantis, 1997; Nakayama & Mackeben, 1989; Olivers & Meeter, 2008). Images presented with the target were on the screen during this period of time and might benefit from this enhancement.

Swallow & Jiang (2011, Exp. 1) tested this hypothesis by presenting the images (faces) for 100 ms (with a 400-ms inter-stimulus interval during which the image was masked) and varying the onset of the square. In the *temporal overlap condition* the faces and squares appeared at the same time, both for 100 ms. In the *square early condition*, the squares appeared 100 ms before the faces. In this condition, the square appeared against the mask of the previous face (Figure 1.26).

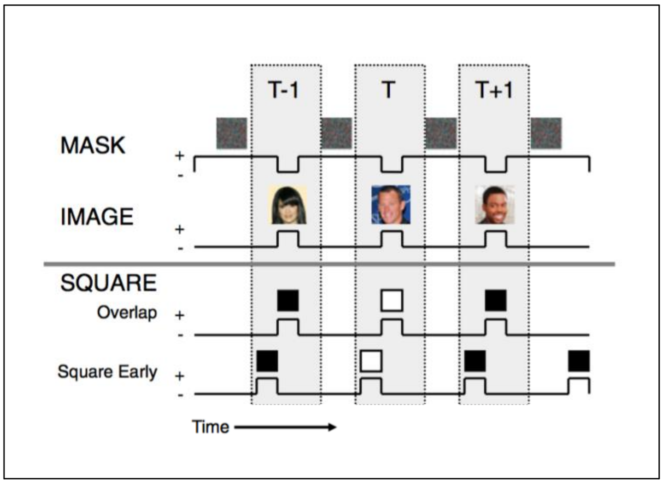

Figure 1.26. Representation of dual task encoding and relative timing of the images, masks, and squares in the different conditions used in Experiment 1 by Swallow & Jiang (2011). The face appeared for 100 ms and then was masked for 400 ms. In the *temporal overlap condition* the square appeared with the face at the same time. In the *square early condition*, the squares appeared 100 ms before the face. In both conditions the square remained for 100 ms.

If the Attentional Boost Effect reflected a perceptual processing enhancement of the image as a consequence of attentional cuing by the target square, then it should be greater in the *square early condition* than in the *temporal overlap condition*. Their results (Figure 1.27) indicated a boost effect only in the *temporal overlap condition*. In this condition, accuracy was greater for images presented at the same time of the target than for images presented at the same time of a distractor. No ABE was found in the *square early condition*.

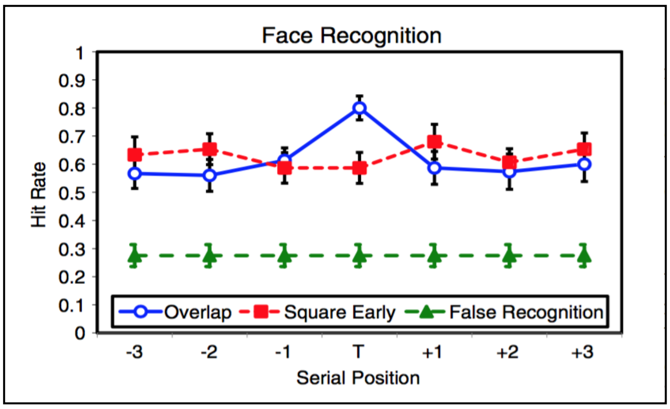

Figure 1.27. Recognition test performance (Hit Rate) for images presented at different Serial Positions relative to the white-square target in the *temporal overlap* and *square early conditions* in Experiment 1 by Swallow & Jiang 2011. False Recognition Rates illustrate the proportion of "old" responses to new images. Bars represent standard errors.

These results did not confirm the *attentional cuing hypothesis*. Because images in the *square early condition* were on the screen 100 ms after the target appeared, they were present when the effects of attentional cuing should have been strongest. However, there was no advantage for images that onset 100 ms after a target relative to those that onset 100 ms after a distractor.

1.1.6.2. Reinforcement learning hypotheses

A second possibility was based on the notion that detecting a target was rewarding (Raymond, Fenske, & Westoboy, 2005; Seitz & Watanabe, 2009). So following the rules of reinforcement learning, scenes that were presented with targets migh be reinforced because they signal a rewarding event. In classical conditioning, information that was predictive or consistently paired with a rewarding stimulus was learned and reinforced in memory, allowing an organism to anticipate that a reward was imminent. In the case of the Attentional Boost Effect (ABE), images that were concurrently presented with the target might be reinforced in memory because they signalled that a rewarding stimulus was present.

Swallow & Jiang (2011, Exp. 2) tested whether targets could enhance memory for images that predicted target onset when those images were the strongest environmental cue of the target (the reinforcement hypothesis). The tasks were the same as those used in Experiment 1, with one exception. The authors compare the *temporal overlap condition*, where the faces and squares appeared at the same time, both for 100 ms, with the *image early condition*, where the squares appeared 100 ms after the faces. If reinforcement learning of predictive information was a central component of the Attentional Boost Effect, then memory for images presented immediately before a target should be enhanced relative to those presented immediately before a distractor (Figure 1.28).

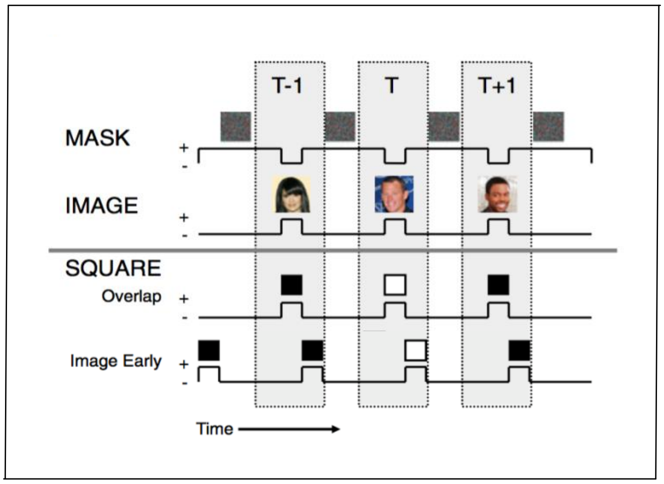

Figure 1.28. Representation of dual task encoding and relative timing of the images, masks, and squares in the different conditions used in Experiment 2 by Swallow & Jiang (2011). The face appeared for 100 ms and then was masked for 400 ms. In the *temporal overlap condition* the square appeared with the face at the same time. In the *image early condition*, the squares appeared 100 ms after the face. In both conditions the square remained for 100 ms.

As in the previous experiment, the authors found an ABE in the *temporal overlap condition*. Critically, there was no advantage for faces presented immediately before targets in the *image early condition* than faces presented immediately before distractors (Figure 1.29).

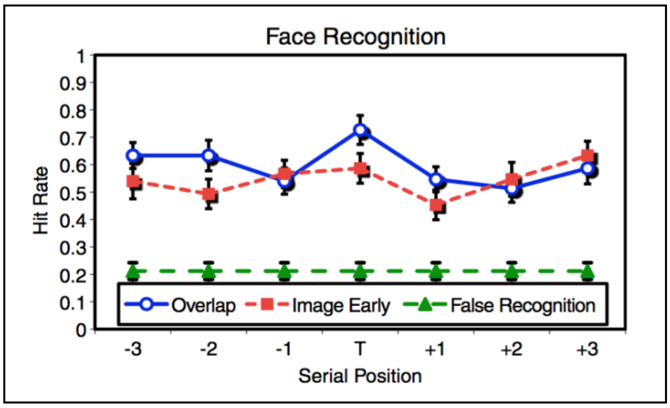

Figure 1.29. Recognition test performance (Hit Rate) for images presented at different Serial Positions relative to the white-square target in the *temporal overlap* and *image early conditions* in Experiment 2 by Swallow & Jiang (2011). False Recognition Rates illustrate the proportion of "old" responses to new images. Bars represent standard errors.

These data were against the *reinforcement learning hypothesis*. In the *image early condition*, the images that were most predictive of target onset were those presented immediately before it. If detecting targets enhanced memory for concurrently presented images through reinforcement learning, then images presented immediately before the target in the *image early condition* should benefit as much as, if not more than, those presented with targets in the *temporal overlap condition* (Swallow & Jiang, 2011). However, the difference in memory for images presented with targets versus images presented with distractors was far greater when they temporally overlapped than when the image appeared before the target.

1.1.6.3. Perceptual grouping hypotheses

A final mechanism that may account for the Attentional Boost Effect (ABE) was the perceptual grouping of the background image with the target square. In previous experiments (Swallow & Jiang, 2010), the background image and the square onset at the same time. Visual stimuli whose features vary according to the same temporal schedule tend to be perceived as a single group or object (Alais, Blake, & Lee, 1998; Jiang, Chun, & Marks, 2002). If images and targets were grouped together into the same perceptual entity, then increasing attention to one part of the group, the target, should also have led to increased attention to another part of the group, the background image (Driver & Baylis, 1989).

Swallow & Jiang (2011, Exp. 3) tested this hypothesis in an experiment where square and face were always overlapped in time, but changing the synchronicity with which the two stimuli appeared. The faces were presented for 500 ms, with no inter-trial interval. In the *common onset condition* the faces and squares appeared at the same time. After 100 ms, the square disappeared and the face was presented on its own for another 400 ms. In the *separate onset condition*, the face was presented on its own for 100 ms, then with the square for 100 ms, and then on its own for an additional 300 ms. Because the common onset is a temporal grouping cues, it should strengthen perceptual grouping and any effects it has on later memory for the images. Results (Figure 1.30) indicated that recognition memory was best for images presented with targets, and this effect was similar in the common onset and separate onset conditions.

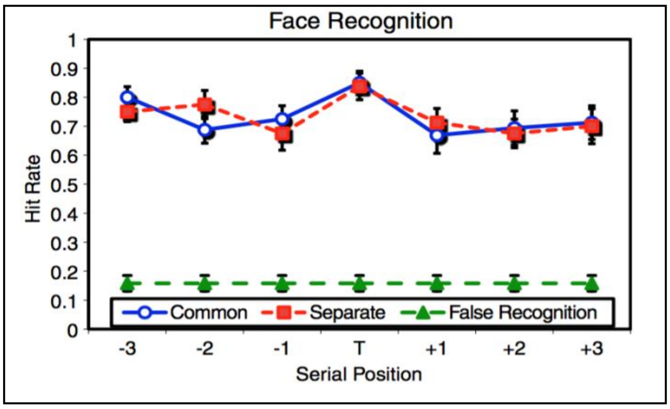

Figure 1.30. Recognition test performance (Hit Rate) for images presented at different Serial Positions relative to the white-square target in the *common onset* and *separate onset conditions* in Experiment 3 by Swallow & Jiang (2011). False Recognition Rates illustrate the proportion of “old” responses to new images. Bars represent standard errors.

If the Attentional Boost Effect reflects grouping of the images and squares into a single entity, then it may be modulated by the presence of a grouping cue. One powerful temporal grouping cue is temporal synchrony and common onset. When visual stimuli appear at the same time, they tend to be perceived as a single group (Alais et al., 1998; Jiang et al., 2002; Sekuler & Bennett, 2001). Removing the common onset grouping cue should decrease the likelihood that the images are grouped with the squares and eliminate or decrease the magnitude of the ABE. The data did not support this prediction, however, suggesting that temporal synchrony does not play a critical role in the Attentional Boost Effect. Another evidence contrary to the perceptual grouping hypothesis is that the ABE occurs when a target is defined by the conjunction of form and colour features (Swallow & Jiang, 2010). The form identification interferes with perceptual grouping (Ben-Av, Sagi, & Braun, 1992). Thus, the Attentional Boost Effect occurs despite task demands that interfere with perceptual grouping and in the absence of two powerful temporal grouping cues.

1.1.6.4. Temporal overlapping is sufficient?

Previous experiment (paragraph 1.1.6.3) have clearly demonstrated that the Attentional Boost Effect (ABE) did not depend on the common onset of images and targets, but depended on the images and targets overlapping in time. Swallow & Jiang (2011, Exp. 4) wanted to verify if the temporal overlapping was not only a necessary, but also, a sufficient condition for the ABE.

To do this, two different groups of participants performed the continuous detection task under the *common onset condition* described above (Swallow & Jiang, 2011, Exp. 3): faces and squares appeared at the same time; after 100 ms, the square disappeared and the face was presented on its own for another 400 ms. One group was told that they would make judgments about the background images after they completed the detection task (*image-relevant group*). The other group was told to ignore the background images and that attending to them may hurt their performance on the detection task (*image-irrelevant group*). If temporal overlap was sufficient to enhance memory for images presented with targets when they were task-irrelevant, then the ABE should be present in both groups. However, if attention to the background image modulated the Attentional Boost Effect, then it should be significantly weakened in the image-irrelevant group. The results indicated that the benefit of presenting an image at the same time as a target was evident only when the image was task-relevant (Figure 1.31).

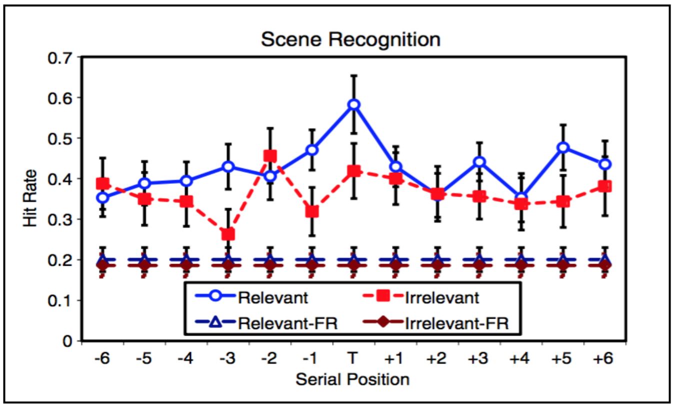

Figure 1.31. Recognition test performance (Hit Rate) for images presented at different serial positions relative to the white-square target during encoding in Experiment 4 by Swallow & Jiang (2011). False Recognition Rates (Relevant-FR and Irrelevant-FR) illustrate the proportion of “old” responses to new images for the different groups. Bars represent standard errors.

This data suggested that the ABE was modulated by attention to the background image.

1.1.6.5. Conclusions

Swallow and Jiang (2011) demonstrated that the attentional cuing, the reinforcement learning and the perceptual grouping hypothesis could not fully explain the Attentional Boost Effect (ABE) in a completely manner:

- targets and context images had to overlap in time for the enhancement of memory: targets appearing 100 ms before or 100 ms after the image without temporal overlap did not facilitate memory of the contextual image;

- target and images did not need to be synchronized: no need of common onset for target and context image, which is an important grouping cue;
- the overlap of the target and context image was not sufficient: focused attention to targets did not enhance memory for task-irrelevant images when participants were asked to ignore background scenes.

The authors concluded that focused attention to target did not boost background scene encoding under all circumstances and it could be intentionally inhibited (Swallow and Jiang, 2011).

1.1.7. Conclusions and final interpretations of the Attentional Boost Effect

The Attentional Boost Effect (ABE) is a counterintuitive phenomenon where the division of the attention improves the later memory (Swallow & Jiang, 2010; see Swallow & Jiang, 2013, for a review): items presented with targets were better remembered than items presented at the same time with distractors.

This advantage has been obtained with different type of materials (pictures – scenes, objects, faces – and words) (Swallow & Jiang 2010, 2011, 2012; Spataro et al., 2013), in different modalities of the detection and memory task (visual and auditory tasks) (Swallow & Jiang, 2010; Mulligan, Spataro, Picklesimer, 2014). Why the effect to occur, target and item needed to be temporally, but not spatially overlapped (Swallow & Jiang, 2011; Makovski et al., 2011; Spataro et al., 2013), and participants had to pay attention to both the detection and the memory task (Swallow & Jiang, 2010, 2011). The effect could be obtained even if the target was frequent as distractor and if participants processed the target without making an overt response (e.g., by silently counting the targets) (Swallow & Jiang, 2010; 2012).

These studies ruled out a number of potential accounts of the effect. The lack of an ABE in the full attention (FA) condition indicated that the effect was not due to the perceptual saliency of the infrequent targets (squares or circles), but rather that these cues (squares or circles) must be processed as targets (e.g., responded to) for the ABE to be produced (Swallow & Jiang, 2010; see also Makovski, Jiang, & Swallow, 2013). Data on ABE were also inconsistent with simple accounts of the Attentional Boost Effect based on attentional cuing, learning of reward-predictive information, and perceptual grouping (Swallow & Jiang, 2011).

1.1.7.1. The dual-task interaction model

To account for their findings, Swallow and Jiang (2013) proposed the so-called *dual-task interaction model* (Figure 1.32). This framework assumes that, on each trial, information from the squares and the background stimuli compete for representation in the primary visual cortex, producing a first source of interference. In particular, processes specific to the squares (processes triggered by the recognition that an item is a target, and therefore require a response, or a distractor, which therefore require no response) interfere with the ability to encode the concurrent image (*item-specific interference*). In addition, a second source of interference results from the need to maintain two simultaneous goals in working memory: encoding the background stimuli into memory and generating an appropriate response to the square (*task-specific interference*). To resolve this competition, a cognitive control system like the central executive prioritizes the elaboration of the goal-relevant items (i.e., the to-be-responded squares). The rapid categorization of targets as stimuli that require an overt response triggers *temporal selective attention* (Olivers & Meeter, 2008), a mechanism that is temporally, but not modality or spatially selective. The temporal selective attention enhances the processing of all perceptual information that is present when a target occurs. The authors hypothesized that this mechanism is based on a transient increase in the release of norepinephrine from the locus coeruleus – a nucleus in the brainstem which has widespread connections with many cortical regions, including the hippocampus and the occipital cortices (Aston-Jones & Cohen, 2005; Nieuwenhuis, Gilzenrat, Holmes, & Cohen, 2005).

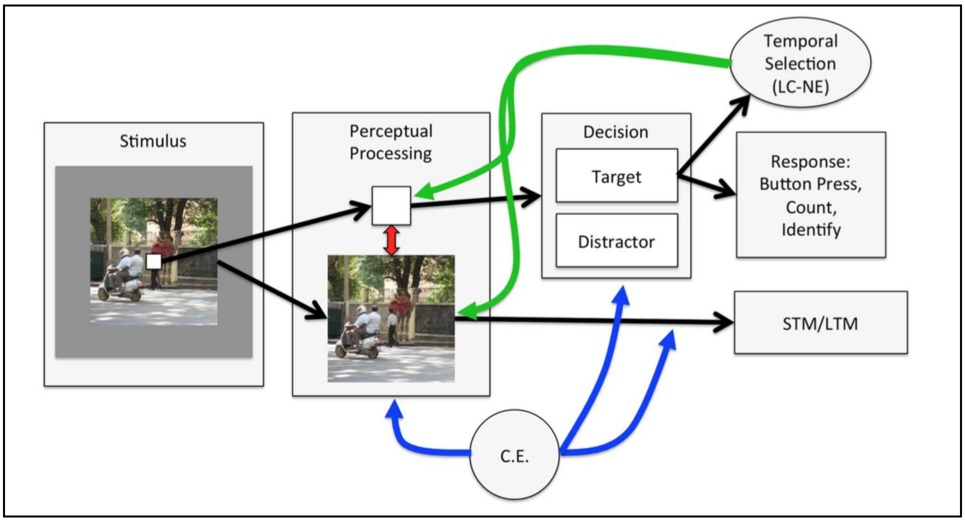

Figure 1.32. The dual-task interaction model. On each trial, sensory information from the two task-relevant stimuli is selected to undergo perceptual processing (early selection), as directed by the central executive (C.E.). Within perceptual processing areas, the two stimuli compete for representation, producing dual-task interference. Dual-task interference also arises from the need to maintain multiple goals simultaneously: the encoding task and the detection task. Perceptual evidence that the square is a target or distractor is accumulated, and the square is categorized once a threshold has been reached. The item may then be selected to guide behavior and be maintained in memory if necessary (late selection).

The dual-task interaction model made it clear that the ABE represents a dynamic trade-off between an *attentional competition* (items in the DA-distractor condition were recognized worse than FA performance – the typical negative interfering effect of DA on memory encoding) and an *attentional boost* (items in the DA-target condition were boosted to the level of FA performance), with the latter dominating under specific circumstances (Spataro et al., 2013; Swallow & Jiang, 2010). In support of this claim, Swallow and Jiang (2010, Exp.5; paragraph 1.1.2) reported that a modest increase in attentional competition during the target detection task (when responses were arbitrarily mapped to the targets) was sufficient to eliminate the ABE.

1.1.7.2. Two different interpretation for the Attentional Boost Effect

Swallow & Jiang (2010, 2013) thought that at the base of the ABE there was an enhanced perceptual encoding of co-occurring stimulus. This *perceptual encoding hypothesis* proposed not simply that the attentional boost manipulation enhanced encoding of perceptual information, but that such enhanced perceptual encoding was the source of the memory benefits (Spataro et al., 2013). This hypothesis was consistent with the extant data on ABE with pictures (Swallow & Jiang, 2010, 2011, 2012). Likewise, the results of Spataro et al. (2013) using verbal materials can be accommodated by this account. They found an ABE with verbal materials using two perceptual implicit memory tests (word fragment completion and lexical decision tasks), but not with a conceptually driven implicit test (semantic classification test). Since the conceptual priming is relatively sensitive to prior conceptual but not perceptual encoding, this result was consistent with the hypothesis that the facilitation produced by the target detection affected processing of perceptual, and not semantic, information. The perceptual hypothesis could be also coherent with the results in the explicit recognition test found by Spataro et al. (2013, Exp.1). According to the *dual-process model* (Yonelinas, 2002), the recognition memory is sensitive to both semantic and elaborative processing on the one hand, and perceptual fluency processes on the other. Consequently, it was possible that the ABE in perceptual priming and in the recognition memory with verbal materials was attributable to a single cause: enhanced perceptual processing of the words in the DA-target condition.

Results by Mulligan et al. (2014) indicated that the supposed perceptual enhancement consequently to the attentional orienting response was not specific for sensory modality: the ABE could be presented both for visual and auditory items in the memory task. This view was also supported by a neuroimaging study that showed that when participants processed a visual target in the detection task, activity in auditory primary cortex was enhanced, while when was processed an auditory target, was enhanced the activity in visual primary cortex (Swallow et al., 2012).

However, Mulligan et al. (2014) also presented results in contrast with the *perceptual enhanced hypothesis*. If the ABE was mediated by enhanced perceptual encoding of items that accompanied the target, the effect should show a substantial degree of perceptual specificity. Consequently, it should be influenced by the change in the sensory modality between the encoding and the test phase. As said before, in agreement with the *dual-process model* (Yonelinas, 2002), the recognition is characterized by a perceptual fluency contribution. Therefore, the condition with the greater visual encoding (i.e., the DA-target condition) should produce greater perceptual fluency at test and thus higher recognition accuracy. However, if the modality was different between study and test, then the amount of perceptual fluency should be reduced or eliminated, and any memory effect mediated by perceptual fluency, as the ABE, should be similarly affected. Mulligan et al. (2014, Exp. 1-3) combined different sensory modalities (visual and auditory) of the words in the memory task between the encoding and the test phase. They found a robust ABE not only in the *modality match condition* (where encoding and test phases had the same sensory modality – e.g., both study and test phase visual or auditory), but also in the *modality mismatch condition* (where encoding and test phases had different sensory modality – e.g., visual study phase and auditory test phase or vice versa). Moreover, the ABE was of the same magnitude in the two modality conditions (Figure 1.33).

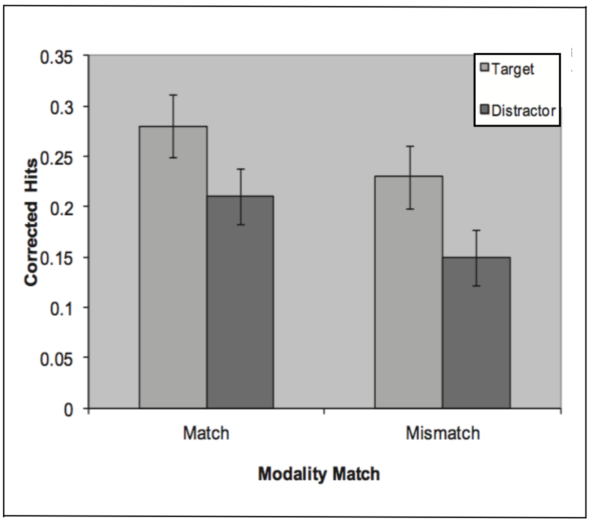

Figure 1.33. Mean Corrected Hits as a function of Modality Match (Match vs. Mismatch) and Trial Type (Target vs. Distractor) in the Experiment 3 by Mulligan et al. (2014). Bars represent standard errors. In the match condition, encoding and test phases had the same sensory modality (both visual or auditory). In the mismatch condition, encoding and test phases had different sensory modality (visual encoding and auditory test or vice versa).

These results argued against the more general version of the perceptual encoding account, which proposed that enhanced perceptual encoding of the word (in whichever modality it was presented) produced the ABE.

Another evidence against the *perceptual encoding hypothesis* was the presence of the Attentional Boost Effect (ABE) in free recall (Mulligan et al., 2014). Generally, to the extent that variation in perceptual encoding of words impacts explicit memory, the effects are more likely in recognition than in free recall (for review, see Mulligan & Osborn, 2009; Parks, 2013). Furthermore, from a theoretical perspective, the *dual-process model* argues that perceptual fluency (and thus perceptually mediated effects) does not contribute to free recall because there is no overt test stimulus to be perceived, and thus no opportunity for perceptual fluency to provide a familiarity signal (Jacoby, 1991; Parks, 2013; Yonelinas, 2002). Then, according to the *perceptual encoding hypothesis*, if the ABE was based on enhanced perceptual encoding of the word, the effect was unlikely to occur in free recall. Results of Mulligan at al. (2014) contradicted this implication, showing a robust ABE in free recall. They compared a DA and a FA condition: the ABE was found only in the DA condition, and the boost for the target words in this condition was a relative effect, bringing the recall up to the level of the FA condition (see paragraph 1.1.3).

If the perceptual enhancement could explain the attentional boost manipulation with the perceptual priming results, it was not sufficient to accommodate the ABE in explicit memory with verbal materials. Mulligan and colleagues (2014) hypothesized that the ABE enhance other forms of information about stimuli that co-occur with targets. They excluded the semantic processes. Indeed, the ABE was present with brief study trial (800 ms in Mulligan et al., 2014; 500 ms in Spataro et al., 2013, and Swallow & Jiang, 2010; 400 ms in Mulligan & Spataro, 2015). Semantic elaboration is typically conceived of as a controlled rehearsal process that unfolds over time. The study times of the attentional boost experiments seemed too brief to allow for substantial, differential semantic elaboration. Furthermore, the ABE was not found in a conceptual implicit test (Spataro et al., 2013), providing additional evidence that the attentional boost manipulation was not based on semantic elaboration. Mulligan et al. (2014) proposed that the ABE was based on the enhancement of the binding between an amodal and abstract word representation and the spatiotemporal context. They hypothesized an amodal representation because the ABE has been shown to be independent of the sensory modality of stimuli.

This form of contextual binding encoding was critical for performance in explicit test of recognition and recall, was hypothesized to be deeply involved in the episodic memory (e.g., Howard, Fotedar, Datey, & Hasselmo, 2005; Polyn, Norman, & Kahana, 2009; Raaijmakers & Shiffrin, 1981), and represented a prominent function of the hippocampus (Howard, Kumaran, Ólafsdóttir, & Spiers, 2011). Several studies provided some evidence in support of this speculative hypothesis. A study with schizophrenic patients (Rossi-Arnaud et al., 2014) showed that these patients did not show the ABE. Schizophrenia is a pathology associated with deficits of contextual binding processes (Diaz-Asper et al., 2008), and for whom structural and functional abnormalities of the hippocampus have been consistently documented (Heckers & Konradi, 2010). The results on the ABE with low-frequency (LF) word could also support the possibility that the attentional boost manipulation enhances context binding. Mulligan et al. (2014) showed that ABE was no present with low frequency words. Thus, whatever facilitation processing accrues to words in the target condition could be redundant with the processing that typically happens with LF words. One advantage for the LF words was better memory for source information's and contextual details. This advantage has been linked to the superior recognition memory for LF words (e.g., Guttentag & Carroll, 1994, 1997; Marsh et al., 2006). Given that higher degrees of context binding occur for LF words already (as reflected by their greater source and context memory), then the attentional boost manipulation might not add much to this aspect of the memory trace for these items. Then, the results that the attentional boost manipulation enhanced memory for high frequency (HF) words but had little effect on LF words was consistent with the possibility that the attentional boost manipulation enhanced the binding between the word representation and the contextual information.

1.1.7.3. Summarizing

In conclusion, in the Attentional Boost Effect (ABE), stimuli encoded with a target (an event that required a response) were better memorized, overcoming the negative effect of the division of the attention typically-observed in a dual task paradigm.

Swallow & Jiang (2010) explained their results hypothesizing that detecting a goal-relevant events (such as the appearance of a target that require a response in a stream of distractors) might induce an attentional orienting response (oriented the attention to the moment in time that the event occurred). This attentional orienting response might open an attentional gate that facilitates the perceptual processing and encoding of both primary (memory task) and secondary task (detection task) information into memory (perceptual enhanced hypothesis). Then, for the authors (Swallow & Jiang 2010, 2011, 2012; Spataro et al., 2013), the perceptual enhancement was the source of the memory benefit in the ABE paradigm.

However, if this hypothesis was coherent with the data obtained using pictorial material and verbal materials in implicit tasks in the attentional boost manipulation, data with verbal materials in explicit tasks seemed requiring additional explanations. In particular, Mulligan, Picklesimer & Spataro (2014) proposed that the ABE enhanced other forms of information about stimuli that co-occur with target. Based on previous results (Swallow & Jiang, 2010; Spataro et al., 2013; Mulligan et al., 2014), they excluded semantic processes and hypothesized that the ABE enhanced the context binding with an amodal word representation.

1.2. Natural changes in healthy elderly

1.2.1. Introduction

Evidence from various studies in the literature suggested that normal ageing processes involve physiological, neuronal and cognitive changes. These age-related changes, in particular in brain structure and function as well as in cognition, are not uniform across the whole brain, across all cognitive domains or across individuals. For example, although cognitive decline was usually reported in the aging literature, many older people outperformed, at least in some cognitive task, young people or did at least as well as the young (Craik et al., 1992).

1.2.2. Physiological changes in aging

The physiological decline of the body was probably the change most evident during aging. These physiological changes were part of normal (non- pathological) aging and occur in all organ systems (for example, Janssens, Pache & Nicod, 1999; Weinstein & Anderson, 2010; Pugh & Wei, 2011). Consequently, also the sensory abilities were affected by aging (Richard et al., 1984; Thornbury & Mistretta, 1981; Chauhan et al., 1987; Willott & Lister, 2003; Blanks & Dorey, 2009). Older people were characterized by impaired visual acuity, contrast sensitivity, and colour vision. Optical changes, changes in the retina or in the central visual pathway could contribute to the visual abilities decline (Spear, 1993).

A very useful paradigm to test the integrity of the visual sensory system was the UFOV (Useful Field of View) test (Edwards et al., 2006). UFOV referred to the visual field area over which information could be acquired in a brief glance without eye or head movements (Ball & Owsley, 1993). The UFOV was influenced not only by sensory factors, but also by cognitive factors. Indeed, performance on this test was correlated with mental state (Ball et al., 1993) and with neuropsychological measures of cognitive abilities (Goode et al., 1998). The standard measure of the UFOV was to locate a peripheral stimulus presented on a uniform field. The UFOV was considerably decreased with the increment of the task difficulty, by embedding the peripheral target within distractors or by joining the peripheral localization task with a foveal discrimination task at the same time (Ikeda & Takeuchi, 1975; Williams, 1982; Sekuler & Ball, 1986). Sekuler, Bennett & Mamelak (2000) compared performances of subjects ranging in age from 15 to 84 in three different tasks: a central localization task, a peripheral localization task and a dived attention (DA) condition where participants performed the central and the peripheral task at the same time. Results indicated gradually age-related changes in the UFOV across the life span. Accuracy in both central and peripheral localization tasks decreased with age. Moreover, in the DA condition participants had always a poorer performance in the peripheral task. But the effect of the attentional condition on the peripheral localization differed significantly as a function of age. Indeed, older people generally suffered more from DA than younger subjects (Anderson, Craik, & Naveh-Benjamin, 1998; Anderson et al., 2000; Castel & Craik, 2003; Naveh-Benjamin, Craik, Guez, & Kreuger, 2005). The authors concluded that the UFOV of older observers was particular sensitive to attentional load.

1.2.3. Neural changes in aging

1.2.3.1. Functional changes

Functional MRI (fMRI) studies have provided ample evidence of age differences in task-related brain activity (Spreng et al., 2012; Eyler et al., 2011). Recent studies showed different activation patterns between young and healthy old groups using a variety of cognitive task (Maillet & Rajah, 2014; Spreng et al, 2010). Older adults utilized some brain areas in common with younger adults during cognitive tasks, although sometimes to a lesser degree, but also recruited additional regions (Logan et al., 2002; Maillet & Rajah 2014; Spreng et al., 2010). Sometimes brain activity was reduced in older adults relative to younger adults and sometimes it was increased. Decreased brain activity had typically been interpreted as a reflection of cognitive deficits in older adults (Grady et al., 1995), and increased activity had often been interpreted as compensatory mechanism (Grady et al., 1994). Most of the studies showed an additional prefrontal recruitment, often accompanied by a decreased activity in occipital-temporal areas (Grady et al., 1994) - a phenomenon termed as "*posterior–anterior shift with ageing*" (PASA, Davis et al., 2008). These reorganizations were usually attributed to a compensatory role, particularly in the cases which the older adults showed preserved cognitive ability. Indeed, the recruitment of prefrontal regions during some tasks in the elderly might indicate an increased need for executive functions in this group, such as monitoring of responses or attentional demand (for a review, Grady, 2000).

In general, a compensatory interpretation was often invoked when older adults show higher activation in a brain region than younger adults ,while they perform a task at the same level as younger adults (Cabeza & Anderson, 2002), or when increased activity was positively correlated with performance in older adults but not in younger adults (Della Maggiore et al., 2000; Grady et al., 2005). Other studies suggested that compensatory mechanisms might still be involved even when performance in older adults was impaired. For example, Zarahn et al., (2007) claimed that increased activity in an older adult might not be associated with preserved performance on a given task to the level seen in a young adult, but this performance might be even worse without the over-recruitment.

In general, several works have provided evidence in favour of the compensatory hypothesis. Vallesi et al. (2011) examined age differences in inhibition in different tasks that assessed the ability to inhibit prepotent responses. Older adults, compared with young adults, displayed more activity in a set of dorsal prefrontal cortex (dPFC) and parietal regions that could be identified with the dorsal attentional network (Corbetta et al., 2008); importantly, activity in these attentional regions correlated with better inhibition only in older adults. Similarly, Lee et al. (2011) examined face perception and found a set of regions in the right PFC and occipital cortex where increased activity was associated with better face recognition in older adults but not in the younger group. These results were consistent with the idea of a compensatory mechanism through which the additional activity in task-relevant regions increaseed the ability of older adults to carry out the task.

However, there were other works that provided evidence that over-recruitment of brain activity did not necessarily lead to a better task performance. More brain activation in older adults could sometimes be associated with poorer, and not better, performance (Stevens et al., 2008). Recent studies have reported in older adults greater activity in the PFC during memory encoding (de Chastelaine et al., 2011) and retrieval (Persson et al., 2011) that were correlated with poorer memory. Similarly, higher activity in a distributed set of regions, including the PFC and parietal cortex, was found to be correlated with slower and more variable reaction times on a set of visual tasks in old adults compared to young adults (Garret et al., 2011; Grady et al., 2010).

Together, these results suggested that increased activity in older relative to younger adults could be associated with better performance on some tasks. However, this additional brain activity was not always compensatory (in the sense that it is directly related to better task performance). In some cases, over-recruitment of brain areas could reflected a greater demand on neural resources or less efficient use of them, or a reduction in the selectivity of responses (Grady et al., 2008).

1.2.3.2. Structural changes

Several studies showed structural alteration in grey (Raz, 2000) and white (Sullivan and Pfefferbaum, 2006) matter integrity in healthy aging, and their relationships with functional and cognitive results.

Post-mortem and *in vivo* studies showed a lower volume of the grey matter in the brain of older adults compared to the grey matter volume of younger adults (Haug & Eggers, 1991; Resnick et al., 2003). The cause of this volume declines seemed to result not from cell death, but rather from lower synaptic densities (Terry, 2000). Regional changes in volume were not uniform. Some regions, such as the prefrontal cortex (PFC) and medial temporal structures, are more vulnerable to the both normal and pathological ageing, while other regions, such as the occipital cortex, remaining relatively unaffected (Raz et al., 2004; Raz et al., 2003; West, 1996). Age differences in grey matter volumes has been associated with reduced functional activation (Thomsen et al., 2004). For example, in one recent study, Rajh et al. (2011) assessed the relationship between age reductions in grey matter volume of a region in the right middle frontal gyrus (MFG) and brain activity. In young adults, larger right MFG volume was positively correlated with greater activity in the bilateral dorso-lateral PFC and inferior parietal cortex, areas implicated in memory retrieval (Cabeza et al., 2008; Lepage et al., 2000). In older adults, right MFG volume was negatively correlated with activity in several regions, including the parahippocampal cortex. Less activity in these regions predicted better memory in older adults. Rajh and colleagues (2011) interpreted these results suggesting that older adults with larger right MFG volume might be able to compensate for the effects of age on this region by modifying activity in other brain regions to help memory retrieval. In agreement with the authors' interpretation, the compensation appeared to take the form of decreased activity in some regions, which may indicate suppression of processes that would conflict with memory retrieval. In another study, Kalpouzos et al. (2012) assessed the relation between brain activity and grey matter volume in younger and older adults across the whole brain during a memory task. Results showed an under-recruitment of the occipital cortex during encoding of face–name pairs in old adults compared to young adults, which was mostly accounted for atrophy in these regions. At retrieval, older adults over-recruited several regions, including dorsolateral PFC and parietal cortex. This over-recruitment was eliminated after accounting for volume loss only for the differences in the PFC volume, not where was accounted for by atrophy in the parietal cortex. The authors concluded that structural age changes might account for some, but not all, of the differences in brain activity between older and younger adults. In conclusion, all these studies indicated that brain structural differences due to the age could influence the relationship between activity in task-related brain regions and behaviour, indicating a complex interplay between structure and function.

The relationship between structural integrity and functional activation and behaviour has been examined also considering white matter tracts. Chen et al. (2009) showed that the stronger functional connectivity in a network involving the inferior PFC was associated both with better integrity of the corpus callosum and faster response times in older adults. Persson et al. (2006) conducted a longitudinal study where they showed that both the hippocampal volume and integrity of white matter in the corpus callosum were reduced in older adults and correlated with declining memory performance. In the end, Salami et al. (2012) in their DTI (diffusion tensor imaging) study found a decline of the tracts integrity across the entire white matter skeleton as well as in specific tracts. More important, white matter integrity was related to speed of performance in older adults. All these studies indicated that white matter deterioration contributes to a disconnection among distributed brain networks and may mediate age-related cognitive decline.

1.2.4. Cognitive changes

Several differences between young and old people were found in different cognitive tasks. Substantial age-related differences were seen in tasks involving episodic memory (Tulving, 1983; Craik & Bosman, 1992), working memory (Balota et al., 2000; Zacks et al., 2000), attention (Connelly et al., 1991; Allen et al., 1992; Madden, 1990) and task switching (Anderson et al., 1998; Kramer et al., 1999; Cepeda et al., 2001). Older adults were also more susceptible to the effects of distracting interference during cognitive tasks (Hasher & Zacks, 1988; Healey et al., 2008) and had a generally slower processing speed (Salthouse, 1996). These functions tended to decline across the adult lifespan (Craik, 1994). For example, in two cross-sectional studies, processing speed, working memory and episodic memory showed linear life-long declines from 20 to 80 years old, with little or no evidence for accelerated decline in the later decades (Park et al., 1996, 2002). On the contrary, some aspects of cognition, such as well-practiced tasks or tasks that involve knowledge, showed a little or no decline with age until very late in life. For example, some aspects of memory, as measures of vocabulary and semantic knowledge (Laver, 2009; Park et al., 2002) and autobiographical memory (Fromholt et al., 2003), seemed to be unchanged throughout life. Also short-term memory task and implicit memory were often stable with age or showed only little age-related changes (Gregoire & Van der Linden, 1997; La Voie & Light, 1994).

The basic cognitive functions most affected by age are attention and memory (Glisky, 2007). Neither of these are unitary functions, however, and evidence suggested that some aspects of attention and memory remained fairly intact with age while others showed significant declines.

1.2.4.1. Attention

Older adults showed significant impairments on attentional tasks that required dividing or switching of attention among multiple inputs or tasks (for a review see Glisky, 2007). They showed relative preservation of performance on tasks that required selection of relevant stimuli. In general, older adults appeared to be slower than younger adults in responding to targets, but this deficit could be largely attributed to a general slowing of information processing rather than a selective attention deficit (McDowd & Shaw, 2000; Verhaeghen & Cerella, 2002). They also were able to maintain concentration for an extended period of time: older adult's performance on vigilance task usually did not differ from that of younger subjects, except for stimuli highly degraded (Parasuraman, Nestor & Greenwood, 1989).

The tasks on which older adults showed impairments tended to be those that required flexible control of attention, such as divided attention and set shifting tasks (McDowd & Craik, 1988; Verhaeghen & Cerella, 2002). Divided attention tasks required the processing of two or more sources of information or the performance of two or more tasks at the same time. Results obtained using this paradigm suggested that older adults were more affected by the division of attention than young adults (Anderson, Craik, & Naveh-Benjamin, 1998; Anderson et al., 2000). In addition, older adults seemed less able to allocate resources appropriately when instructions were given to vary task priority (Tsang & Shaner, 1998). These findings were usually explained in terms of declining processing resources associated with normal aging (Craik & Byrd, 1982; Rabinowitz, Craik & Ackerman, 1982). Such limited resources were over-extended in older adults when attention must be divided between two or more sources. Similarly, the performance of older adults was slower to a greater degree than that of young adults when attention must be switched from one task to another, requiring a change of mental set (Verhaeghen & Cerella, 2002).

Interestingly, these types of tasks could be trained and showed benefits of cardiovascular fitness. Indeed, there was evidence that age deficits in divided attention and attention switching could be reduced by practice or extended training (Kramer et al., 1999) and by aerobic exercise (Hawkins & Kramer, 1992). The exact mechanism of such improvements, however, was unclear. In the case of task-specific training, it was possible that some aspects of the tasks become automatic with practice, thus requiring fewer attentional resources. Alternatively, participants might develop strategies with extensive training that reduced the attentional demands of the tasks. It has been hypothesized that cardiovascular fitness might improve the efficiency of neural processes or might provide increased metabolic resources for task performance. Interestingly, the enhancement effects of aerobic exercise appeared to be greatest on tasks involving executive control of attention (Colcombe & Kramer, 2003), which depended largely on prefrontal cortex.

1.2.4.2. Memory

The cognitive domain that had probably received most of the attention in normal aging was memory (for reviews, see Zacks et al., 2000; Kester et al., 2002). It was well established that memory performance declined in older adults, but it was also clear that not all aspects of memory were impaired (Balota, Dolan & Duchek, 2000; Glisky, 2007).

- Short-term memory systems

The research addressing sensory memory in young and older adults indicated that there was relatively little age-related change in these systems (Gilmore, Allan & Royer, 1986; Parkinson and Perry (1980); even in some cases elderly people could get better performance than young people (Kline and Orme- Rogers,1978).

Similar conclusions were reached using short-term paradigm (for a review see Zacks, Hasher, & Li, 2000). For example, Puckett and Stockburger (1988) compared young and old adults in the Brown-Peterson task. In this task, participants were required to remember just three letters for a brief period of time. During the retention interval, participants had to perform secondary task (e.g. subtracting by 3 from a 3-digit number). Puckett and Stockburger (1988) found similar levels of memory for young and older adults across the delays, suggesting not only equivalent primary memory capacity but also comparable rates of forgetting.

Differently from sensory memory and short-term memory, there was ample evidence of age differences across a number of working memory tasks (Craik & Jennings, 1992). The working memory was a limited capacity system that involved the active manipulation of information that was currently being maintained in focal attention (Baddeley, 1986). Salthouse et al. (1989) demonstrated that older adults' performance declined as a function of the increasing complexity of mental operations involved across various tasks that tap working memory (i.e., verbal reasoning, spatial visualization - for reviews, see Park & Hedden, 2001).

- Long-term memory systems

Long-term memory, unlike short-term and working memory, required retrieval of information that was no longer present or being maintained in an active state. This information could have occurred a few minutes ago or been acquired many years ago. This system could be divided into other separate components (Squire,1993).

a) Declarative memory

Episodic memory referred to memory for personally experienced events that occurred in a particular place and at a particular time (Tulving, 1972). It is well established that older adults, relative to younger adults, had more difficulty with episodic memory tasks (Balota, Dolan & Duchek, 2000). These deficits might occur at three distinct stages of episodic memory: encoding (the initial storage of the memory), retention (the maintenance of the memory across time), and retrieval (the utilization of the stored memory). At the encoding phase, older adults might encode new information less meaningfully or with less elaboration, so that memory traces were less distinctive, more similar to others in the memory system, and thereby more difficult to retrieve (Craik, 1983). Alternatively, older people might attend to focal or salient information but failed to take account of peripheral detail, or they might fail to integrate contextual aspects of an experience with central content — what was sometimes referred to as a source memory problem (Glisky, Rubin & Davidson, 2001). Moreover, when older adults were encouraged to form rich and elaborate memory traces during encoding, they were less likely to do so (Rabinowitz & Ackerman, 1982; Craik & Jennings, 1992). Turning to retention, results suggested that when initial encoding was equated there was relatively little difference between older and younger adults in rate of forgetting across retention intervals (Giambra & Arenberg, 1993; Park et al., 1988). Finally, turning to retrieval, there was clear evidence of age-related changes, in particular in free recall test. When retrieval was facilitated by providing additional cues at the time of the memory test, these age differences diminished. Indeed, compared to free recall performances, older adults tended to show deficits to a lesser degree in cued recall and minimally in recognition memory (Craik & McDowd, 1987; Rabinowitz, 1984). Craik (1986) explained these results arguing that the requirement to self-initiate strategic search processes in recall burdens the limited resources of older people. If the environmental support could be provided at retrieval as well as at encoding (by providing good cues or using recognition tests, for example), the resource demands of encoding and retrieval were reduced and age differences were minimal.

Differently from episodic memory studies, several works indicated that older people had performance very similar to young adults in semantic memory tasks (Laver & Burke, 1993). Semantic memory referred to one’s store of general knowledge about the world, including factual information and knowledge of words and concepts (Tulving, 1972).

Similar results were found in autobiographical memory tasks (Ruby, 2000; Fromholt et al., 2003). Autobiographical memory involved memory for one’s personal past and included memories that were both episodic and semantic in nature. More detailed analyses of the nature of the autobiographical information retrieved, however, has suggested that although memory for personal semantics was intact in old age, memory for specific episodic or contextual details about one’s personal past might be impaired (Levine et al., 2002). There might be exceptions to this finding, however. Recent studies demonstrated that older adults remember as much as young adults about the details and circumstances surrounding highly emotional public events (Davidson & Glisky, 2002; Davidson, Cook & Glisky, 2006).

Finally, prospective memory was investigated. Prospective Memory referred to the processes and skills involved in remembering intentions that need to be realized in the future (e.g., remembering to take a dose of medicine at scheduled intervals). Researchers distinguished between prospective tasks that were time-based (taking medicine every 8 hours) and those that were event-based (relaying a message to a friend next time you see her) (Einstein & McDaniel, 1990). Time-based tasks seemed to be more vulnerable to aging revealing the largest age-related deficits (Einstein et al., 1995; for a review see Anderson & Craik, 2000). According to Craik (1986), this type of prospective memory task, as free recall, required more self-initiated retrieval processes, that were particularly difficult for older people.

b) Non Declarative memory

Implicit memory referred to a change in behaviour that occurred as a result of prior experience, although one had no conscious or explicit recollection of that prior experience (Schacter, 1987). In a typical implicit memory task, it was measured the priming effect, an effect for which exposure to a stimulus influenced the response to subsequent stimuli. This influence of stimulation could be exercised at a perceptual, semantic or conceptual level (Kolb & Whishaw, 2009). Interestingly, several studies showed non-significant age differences in a variety of non-declarative repetition priming tasks such as word fragment completion (Light, Singh, & Capps, 1986), speeded lexical decision (Balota & Ferraro, 1996) and category exemplar generation (Light & Albertson, 1986); however, there were some inconsistencies in the literature (i.e., Howard & Howard, 1992; 1997). Anyway, the general conclusion from this area of research was that studies of implicit/non-declarative memory tasks indicated that if one observed age-related changes, these were relatively small compared to declarative tasks such as recall and recognition performance (see LaVoie & Light, 1995, for a summary).

1.2.5. Aging and memory: explanatory hypothesis

Different hypothesises were proposed to explain memory declines observed in healthy elderly (for a review see Balota et al., 2000).

a) Slower speed of processing

According to a speed of processing perspective, aging was accompanied by a general slowing in cognitive processing that appeared to include all components of processing (e.g., Birren, Woods, & Williams, 1980; Cerella, 1985). In particular, Salthouse (1996) demonstrated that the speed of processing accounted for most of the age-related variance in several cognitive tasks. For example, Salthouse (1996b) reported that age was related to a general speed factor (derived from a number of processing speed measures) and to the memory performance. However, age was only weakly related to memory performance after statistically controlling for the effect of processing speed. The authors concluded that probably age was only indirectly related to memory performance and was mediated by speed of processing.

b) Reduced processing (or attentional) resources

Craik (1986; Craik & Byrd, 1982) hypothesized that we had a limited amount of attentional resources available and that this amount was reduced with aging. As results, demanding cognitive processes (such as encoding and retrieval) depleted a greater proportion of available resources in older than in younger adults. Evidence in support of this hypothesis came from studies using divided attention paradigm, in which subjects performed a memory task and a secondary unrelated task at the same time (Anderson, Craik, & Naveh-Benjamin, 1998; Anderson et al., 2000; Castel & Craik, 2003; Naveh-Benjamin, Craik, Guez, & Kreuger, 2005). The idea beyond was that because we have a limited amount of attentional resources and because memory processes were more attentional demanding, fewer attentional resources remained available for the secondary task, resulting in a secondary task performance decrements. Anderson et al. (1998) showed that secondary task performance suffered more the divided attention costs. Moreover, older adults showed greater costs compared to younger adults, coherently with the claim that memory processes are more attention demanding for older adults.

c) Inhibition deficit

Hasher & Zacks (1988) hypothesized that cognitive control involves both excitatory processes to enhance the activation of task-relevant information and inhibitory processes to suppress the activation of distracting task-irrelevant information. They suggested that aging was characterized by a relative sparing of excitatory mechanisms and an impairment of inhibitory mechanisms. In support of this hypothesis, several works showed that older people processed more irrelevant information compared to young people (Conelly, Hasher & Zacks, 1991; Carlson et al., 1995) and that they maintained this distraction information in memory (Hartman & Hasher, 1991). Moreover, older adults were more likely to recall information they have been instructed to forget (Zacks, Radvansky & Hasher, 1996). Thus, deficient inhibitory control might underlie memory decrements in old age.

d) Associative deficit

According to the associative deficit hypothesis (ADH), the old people would find difficult to create and recall the links between the units of information (Naveh-Benjamin, 2000). Naveh-Benjamin (2000) used procedures that allow the independent assessment of memory for component and for associative information. In general, older adults exhibit a significant decline in associative memory but only a small or no decline in component memory, supporting the associative deficit hypothesis. This result was shown for different types of items and relationships (Naveh-Benjamin, Guez, Kilb, & Reedy, 2004; Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003; Naveh-Benjamin, 2000), including inter-item relationships (word pairs, picture pairs, name-face pairs, word-font in which it was presented) as well as intra-item relationships (an item and its context - word and the font in which it was presented). The associative memory deficits in older adults seemed not to be mediated by a failure of inhibitory processes (Guez & Naveh-Benjamin, 2016) or by a decline in the attentional resources (Naveh-Benjamin, Guez & Shulman, 2004; Naveh-Benjamin et al., 2005). Such results supported the idea that associative memory deficits reflected a unique binding failure in older adults and that the creation or use of these bonds between units of information in a memory task was a significant determinant of mnemonic performance in elderly.

1.3. Bipolar disorder

1.3.1. Definition and clinical characteristics

Bipolar disorder (BD) is a mood disorder characterized by mood alterations that include manic or hypomanic (elevation of tone mood), depressive (decline of tone mood), and mixed episodes, with intervals of varying levels of euthymic remission. According to DMS-5 (2014), it is possible to distinguish two main forms of BD:

- bipolar disorder - type I, characterized by depressive episodes and manic episodes;
- bipolar disorder - type 2, characterized by depressive episodes and hypomanic episodes.

Depressive episodes are characterized by lack of interest, loss of appetite, insomnia, fatigability and suicidal thoughts, with a very high rate of completed suicides. Manic episodes are characterized by elevated and often irritable mood, prevalent psychotic features, and increased energy, flight of ideas and rapid speech, over activity and disinhibited behaviour that contributes to high rates of recurring hospitalization. (Lim et al., 2013). The hypomania can be distinguished from mania by the magnitude of the symptoms, that are less severe and disabling and by the absence of psychotic symptoms, particularly delusions.

Neuropsychological studies in bipolar disorder indicated cognitive disturbances during mood episodes, including impairments in executive functions (particularly abstract concept formation, set shifting and planning), sustained attention and inhibitory control, verbal memory and processing speed. The evidence for impairment in visual memory was more variable and appeared dependent on the tests used (Quraishi & Frangou, 2002; Lim et al., 2013).

Neuroimaging studies have documented structural and functional abnormalities in cortical, subcortical, and limbic brain systems (Strakowski et al., 2005; Green et al., 2007; Langan and McDonald, 2009). Longitudinal brain structural MRI studies (Lim et al., 2013) suggested cortical and subcortical abnormalities within networks sub-serving emotional regulation. From structural neuroimaging studies there was evidence of neuroprogressive loss of grey matter volume in prefrontal and anterior cingulate cortex and the subgenual region, with less consistent findings in temporal and subcortical regions such as hippocampus. Two recent studies in symptomatic bipolar patients employing diffusion tensor imaging (DTI) showed evidence of abnormalities in prefrontal white matter tracts (Adler et al., 2004; Beyer et al., 2005). Moreover, the fewer reported longitudinal functional MRI studies suggested neurobiological changes in activation patterns involving front- limbic circuitry which relate to different illness phases and mood states (Lim et al., 2013). Houenou et al. (2011) found increased activity in ventral-limbic brain structures (the parahippocampal gyrus and the amygdala) in patients with BD compared with controls. These results were consistent with Eugene et al. (2014) data according to which lithium influenced an increase in neurotransmission in the superior temporal gyrus, the parahippocampal gyrus, the amygdala, and the cingulate gyrus. A PET study comparing euthymic medicated patients with bipolar disorder with healthy controls showed that resting metabolic rates in bipolar patients were significantly greater than in controls in bilateral amygdala, bilateral parahippocampal gyri, and right anterior temporal cortex (Brooks et al., 2009).

There was growing evidence that individuals with bipolar disorder (BD) also showed cognitive impairments when they were euthymic (remission phase). Several meta-analyses reported impairments in cognitive domains of executive functioning, verbal memory and sustained attention (Robinson et al., 2006; Cullen et al., 2016; Palazzo et al., 2017), although in the latter case there was a certain discrepancy in the literature (Docherty et al., 1996; Hawkins et al., 1997; Ferrier et al., 1999). In particular, one of the most consistently reported findings in euthymic individuals with bipolar disorder was an impairment in verbal episodic memory – the ability to explicitly recollect information encountered in a previous study episode (Graf & Schacter, 1985). Some studies suggested that the executive dysfunctions could contribute to the verbal memory impairment observed in these patients. Rather than being two discrete areas of impairment, it might be that executive deficits impeded effective memory performance by introducing inefficiency in encoding and/or retrieval processes. For example, Deckersbach et al. (2004) reported that verbal learning memory deficits were mediated by semantic clustering encoding, a memory organization strategy. However, they compared BD-type I patients and OCD (obsessive compulsive disorder) patients with a control group. Their results showed that semantic clustering mediated group differences between BP-I and control participants to a lesser extent than it mediated it for OCD participants. They concluded that executive function difficulties such as verbal organization during encoding did not explain the verbal memory impairments quite well that are observed in bipolar patients.

Executive impairment in patients with bipolar disorder might reflect underlying dysfunction in the structural or functional neuroanatomy of the prefrontal cortex (PFC). In a small group of euthymic bipolar patients, Drevets et al. (1997) reported lower volume of the subgenual PFC. Moreover, several diffusion imaging studies indicated abnormalities in the frontal with matter of euthymic bipolar patients (Macritchie et al., 2010; Canales-Rodríguez et al., 2014). Oertel-Knöchel and colleagues (2014) found a positive association between abnormal WM microstructural integrity and the poor performance in executive tasks (less WM integrity was associated with poorer performance). Few studies that have combined functional imaging with executive tasks in euthymic bipolar patients indicated reduced activity in frontal areas in bipolar patients relative to controls, which accorded with the above evidence of structural abnormalities in the frontal lobes (Monks et al., 2004; Strakowski et al., 2004).

In conclusion, patients with the illness demonstrated impairments in several cognitive domains even during the euthymic phase. Martínez-Arán et al. (2004) demonstrated that duration of illness, a history of psychotic symptoms, number of hospitalizations, manic episodes, and suicide attempts were positively related to cognitive impairments. Importantly, the presence of cognitive impairment during euthymic periods was found to negatively influence patients' functional outcome (Burdick et al., 2010). Zarate and colleagues (2000) showed that between 30 and 50% of bipolar patients experience significant social disability that might be related to persistent cognitive impairment. Moreover, several evidence suggested that cognitive impairments exhibited in the euthymic phase were trait markers of the disorder (Bora et al., 2009; Arts et al., 2008). Indeed, cognitive deficits were present in unaffected first degree relatives of bipolar patients who might share genetic vulnerability to the disorder. Bora et al. (2009), in their meta-analysis, found that response inhibition, set shifting, executive function, verbal memory and sustained attention deficits were common features for both patient and relative groups, while processing speed, visual memory and verbal fluency deficits were only observed in patients. The use of mood stabilisers seemed to be not fully responsible for the observed deficits. Indeed, cognitive deficits were evident in euthymic lithium medication-free patients (Goswami et al., 2002), and there were no statistically significant differences in the cognitive performances of euthymic medication free bipolar subjects with those taking mood stabilisers (Joffe et al., 1988). The absence of an association between cognitive impairment and medication dose in euthymic bipolar patients suggested the effects of medication did not fully account for the cognitive impairments observe, supporting the assumption that cognitive impairments exhibited in the euthymic phase were trait markers of the disorder.

1.3.2. Role of the Noradrenergic system in bipolar patients.

Abnormalities in the noradrenergic system were implicated in the pathophysiology of the mood disorders, major depressive disorder (MDD) and bipolar disorder (BD) (for reviews see Ressler and Nemeroff, 1999; Anand and Charney, 2000; van Enkhuizen et al., 2015). Only a few postmortem studies have investigated brain presynaptic noradrenergic levels in mood disorders, but these studies had pointed towards norepinephrine signaling dysregulation (Baumann et al., 1999;

Gos et al., 2008; Klimek et al., 1997; Zhu et al., 1999). A monoaminergic deficit of norepinephrine and serotonin in the LC was described in bipolar, but not unipolar suicide victims (Wiste et al., 2008). Several studies reported the use of antidepressant drugs that involve the treatment of the noradrenergic system in the treatment of bipolar disorder, especially during a depressive phase (for a review see Pacchiarotti et al., 2013). Kurita et al. (2014) demonstrated that peripheral levels of MHPG (3-methoxy-4-hydroxyphenylglycol), a noradrenaline metabolite associated with noradrenaline levels in the brain, were significantly lower in bipolar patients in a maniacal state compared to control subjects and correlated positively with the scores obtained in the Young Mania Rating Scale (YMRS). They suggested that peripheral levels of MHPG could be used as a biomarker for the manic state in BD.

1.3.3. The Attentional Boost Effect in psychiatric disorders

The Attentional Boost Effect (ABE) has been studied in different psychiatric pathologies using both the short- and the long- term paradigm (Levy-Gigi & Kéri, 2012; Kéri, Nagy, Levy-Gigi, & Kelemen, 2013; Szamosi, Levy-Gigi, Kelemen, & Kéri, 2013; Rossi-Arnaud et al., 2014).

Works investigating the short-term ABE used the modified version of Lin et al. (2010), comparing healthy and pathological groups as patients with Post Traumatic Stress Disorder (PTDS) (Levy-Gigi & Kéri, 2012), patients with amnestic Mild Cognitive Impairment (Szamosi, Levy-Gigi, Kelemen, & Kéri, 2013) and patients with Parkinson’s disease (Kéri, Nagy, Levy-Gigi, & Kelemen, 2013). In general, a rapid serial sequence of 16 scenes was presented in each trial. At the centre of four scenes appeared a grey square, two of these had a white target letter inside it (target condition), the other two contained black distractor letters (distractor condition); the remaining 12 scenes were presented without square (baseline condition). Participants were requested to remember target letters and to ignore distractor letters. Following each trial, participants had to recall the target and distractor letters. After the letter recall phase, a two-alternative forced choice recognition test was administered. One of these scenes was from the sequence, whereas the other scene was new. Participants had to choose which of the scenes appeared in the sequence. The test stimulus could be a scene without a letter, with a target letter, or with a distractor letter in the sequence (Figure 1.34).

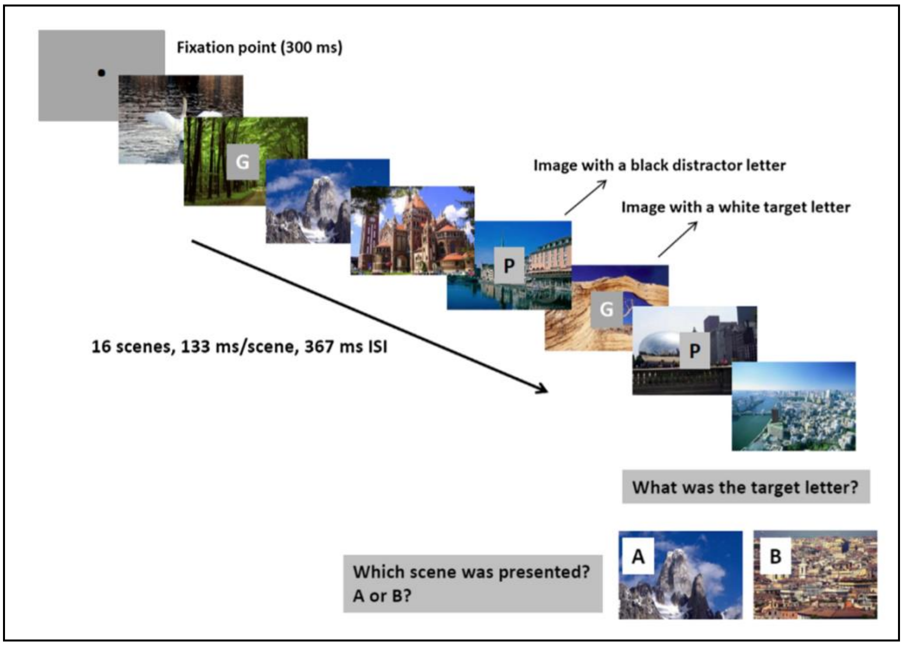

Figure 1.34. Illustration of a trial consisting of a sequence of scenes. Two scenes were presented with white target letters that should be remembered, and two scenes contained black distractor letters that should be omitted. Following the trial, participants first typed the target letter and then chose from the two test scenes. In the auditory condition, target and baseline tones were presented with the scenes, and participants were asked to indicate whether the pitch of the target tones was lower or higher than that of the baseline tones. After the tone discrimination task, participants chose from the two test scenes, as in the case of visual targets. ISI: inter-stimulus interval.

In some studies, authors performed a second experiment using auditory stimuli instead of letters in the oddball task. Stimulus presentation was similar to that described above with the exception that each scene was paired with a brief auditory tone; no letter was presented. 12 scenes were presented with baseline tones having the frequency of 260 Hz (40 dB). Two scenes were presented with target tones with frequency of either 130 Hz (low pitch) or 520 Hz (high pitch). Two scenes appeared together with distractor tones, which were louder than the baseline tones (60 dB). Participants were asked to ignore the distractor tones. Following the trial, the participants had to indicate if the pitch of the target tones were lower or higher than the baseline tones. After the tone discrimination, there was the scene recognition task.

In general, the results showed similar performance between patients and controls in the letter recall and in the tone discrimination tasks, with higher recall and discrimination performances for targets relative to distractors in both groups. Levy-Gigi & Kéri (2012) investigated this phenomenon in a group of patients with Post Traumatic Stress Disorder (PTDS). PTDS patients showed the opposite pattern of performance compared to control: enhanced recognition of scenes presented together with distractors (visual and auditory) and deficient recognition of scenes presented with targets (both with the visual or the auditory version of the oddball task). In a group of aMCI (amnestic Mild Cognitive Impairment), Szamosi et al. (2013) found an improved accuracy for scenes in the target letter condition compared to scenes with distractor letter or scenes alone, but much less pronounced than the one found in the control group. However, using auditory stimuli in the oddball task, patients showed no advantage for scene presented with target tone. In both experiments, controls performed better than aMCI patients when scenes were presented with targets; in the other conditions (scenes alone and scenes with distractors), the two groups did not differ. At the end, Kèri et al. (2013) investigated the boost effect in patients with Parkinson’s disease (PD), testing only the memory for scenes presented with target or distractor letters. The authors recruited a group of newly diagnosed, drug-naive PD patients, evaluated before (baseline time) and after the administration of dopaminergic medications (12-week follow-up period). In the recognition test, at baseline, PD patients had a performance similar to controls: they were able to recognize target-associated scenes as healthy participants. At follow-up, patients with PD outperformed controls for both target- and distractor-associated scenes, but not when scenes were presented without letters. The authors replicated their results in a smaller group of PD patients receiving L-3,4-dihydroxyphenylalanine (L-DOPA).

Until now, only one study investigated the Attentional Boost Effect (ABE) with patients using the long-term paradigm. Rossi-Arnaud and colleagues (2014) examined the ABE in schizophrenic patients using both visual images (Exp. 1) and words (Exp. 2) in the encoding task. In their first experiment, Rossi-Arnaud and collegues (2014) presented a series of pictures with a little square in the centre that could be red (target condition) or, more frequently, grey (distractor condition). They compared two attentional conditions. In the divided attention (DA) condition, participants were instructed to memorize the pictures and to press as quickly as possible whenever they saw an infrequent red circles (targets), but to make no response whenever grey circles (distractors) appeared. The full attention (FA) condition was identical, except that participants were told to ignore the circles and to focus only on the encoding of scenes. In the Experiment 2, authors presented words, instead of pictures, together with squares that could be red (target condition) or green (distractor condition); for the rest, the procedure was the same (Figure 1.35).

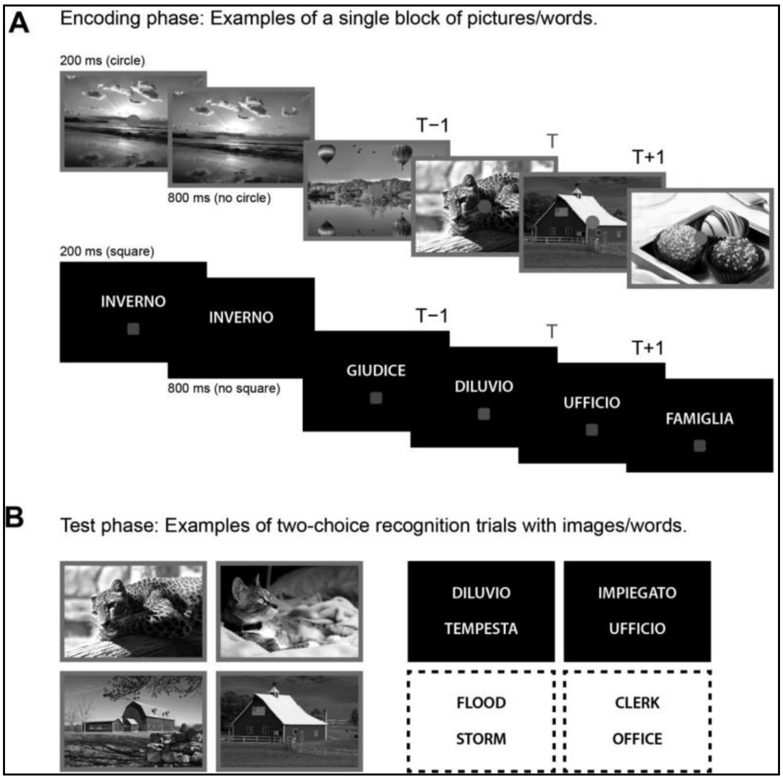

Figure 1.35. Experimental procedure for the encoding and test phases in Experiments 1 and 2 by Rossi-Arnaud (2014). (A) During the encoding phase, participants were simultaneously presented with an image (or a word) and a circle (or a square) for 200 ms, after which only the image (or the word) remained visible for other 800 ms. In the DA condition, participants were instructed to memorize the scenes (or the words) and press the spacebar of the computer as quickly as possible whenever they saw a red circle (or a red square). In the FA condition, participants memorized the scenes (or the words) but ignored the circles (or the squares). (B) During the test phase, participants were presented with pairs of images or words, and told to indicate which of the two stimuli was studied in the encoding phase, by pressing appropriate keys (“1” or “2”).

For both experiments, the results in the detection task indicated an accurate performance in both patients and control subjects, although in the Experiment 2 patients were significantly slower. On the contrary, in the recognition test the two groups had difference performances (see Figure 1.36 and Figure 1.37). Healthy subjects showed the classical relative Attentional Boost Effect (ABE): in the DA condition, stimuli presented with targets were better recognized than stimuli presented with distractors; target stimuli reached the performance obtained in the FA condition, while the distractors stimuli showed the classical interference effect with a lower performance than obtained in the FA condition. For the schizophrenic patients, there were no differences between the performances for target and distractors stimuli in the DA condition; moreover, both target and distractor stimuli were recognized worse than what was obtained in the FA condition.

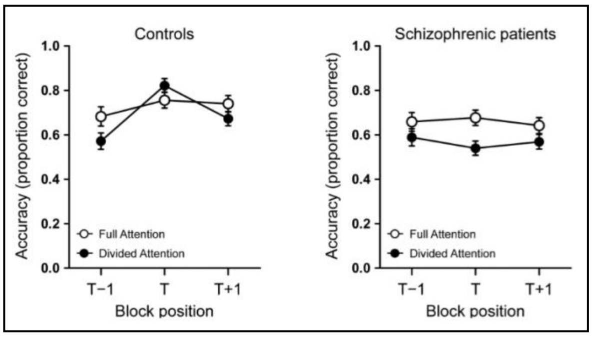

Figure 1.36. Mean Recognition Accuracy of studied images in schizophrenic patients and healthy controls as a function of block position and Attentional Condition (FA vs. DA) in Experiment 1 by Rossi-Arnaud et al. (2014). Bars represent standard errors.

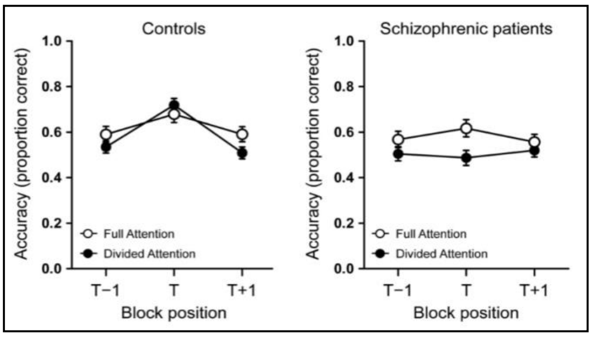

Figure 1.37. Mean Recognition Accuracy of studied words in schizophrenic patients and healthy controls as a function of Block Position and Attentional Condition (FA vs. DA) in Experiment 2 by Rossi-Arnaud et al. (2014). Bars represent standard errors.

In conclusion, data from Rossi-Arnaud et al. (2014) suggested that schizophrenia was associated with a significant reduction in the size of the attentional enhancement induced by the target-mediated boost (Swallow & Jiang, 2013).

1.4. The LC-noradrenergic hypothesis

1.4.1. Introduction

According to Swallow & Jiang (2010), the neural mechanisms involved in increasing attention to the stimuli associated with the targets would be based on a temporary increase in the release of noradrenaline (NE) from the locus coeruleus (LC).

The LC is a nucleus in the brainstem having widespread connections with many cortical regions, including the hippocampus and the occipital cortices (Figure 1.38) (Aston-Jones & Cohen, 2005; Nieuwenhuis, Gilzenrat, Holmes, & Cohen, 2005). Furthermore, LC exhibits substantial regional and laminar specificity in its efferent projections (Morrison et al., 1982). In particular, brain areas that are associated with attentional processing as well as motor responding receive a particularly dense LC-NE innervation (Foote & Morrison, 1987).

LC

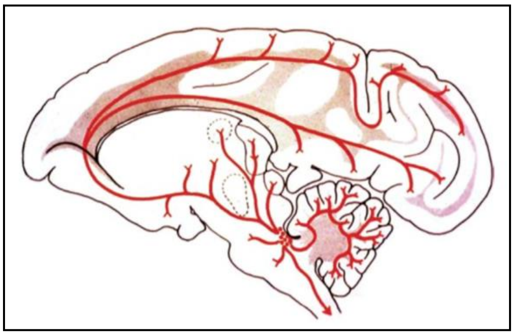

Figure 1.38. Illustration of projections of the LC system. Sagittal view of a monkey brain showing neurons located in the pons with efferent projections throughout the central nervous system. Note that only few areas do not receive LC innervation (e.g., hypothalamus and caudate-putamen). From Aston-Jones & Cohen (2005).

In addition, these neurons exhibit two modes of activity that corresponded to different levels of task performance (Berridge & Waterhouse, 2003; Aston-Jones & Cohen, 2005). In the phasic mode (intermediate tonic activity plus stimulus-evoked phasic activity), the LC system becomes responsive to specific task-relevant stimuli and it is associated with near perfect behavioural performance. In the tonic LC mode (reduction in phasic activity and little or no LC response to target stimuli or other task), such system increases responsivity to a broader class of stimuli, until the behaviour (and attention) becomes relatively indiscriminate and labile (it was associated with poor task performance because of frequent false alarm errors). Aston-Jones (2005) argued that these different modes of LC activity have adaptive advantages under different environmental circumstances. The phasic mode (intermediate tonic activity) may support cortically-driven behaviours optimized to specific stable environments (e.g., tasks requiring focused attention).

Instead, the higher tonic LC activity may be adaptive in changing, or unpredictable environments. That is, the behavioural variability associated with high tonic LC activity may be critical to behavioural flexibility, and responsiveness to unexpected events (Figure 1.39).

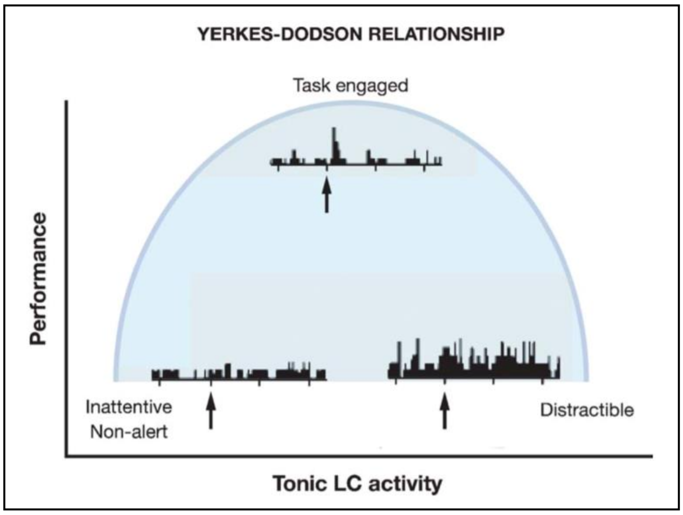

Figure 1.39. Inverted-U relationship between LC activity and performance on tasks that require focused attention by Aston-Jones & Cohen (2005). Performance is poor at very low levels of LC tonic discharge because animals are drowsy and non-alert. Performance is optimal with moderate LC tonic activity and prominent phasic LC activation following goal-relevant stimuli (phasic LC mode). Performance is poor at high levels of tonic LC activity (tonic mode, lacking phasic LC activity). This resembles the classical Yerkes-Dodson relationship between arousal and performance. From Aston-Jones et al. (1999).

1.4.2. Neurobiology of the LC-NE system

A large body of literature implicates noradrenaline in cellular excitability, synaptic plasticity and long-term potentiation (LTP) (for reviews see Harley, 1987, 2007). An equally large number of studies have demonstrated the role of noradrenaline in gating and tuning sensory signals in the thalamus and the cortex (see Berridge & Waterhouse, 2003, for a review).

The modulatory effect of noradrenaline on cellular responses has been examined in awake monkeys that were presented with a series of conspecific vocalizations that elicited an evoked response in the auditory cortex (Foote et al., 1975). If noradrenaline was applied to the auditory neuron by iontophoresis (pharmaceutical administration through the epidermis using a direct current produced by a special generator) before the stimulus was presented, it induced a decrease in spontaneous activity but spared the evoked response to the auditory signal - an effect interpreted as a net increase in the ‘signal-to-noise’ ratio. Additional work in cerebellum, hippocampus, and thalamus demonstrated that increasing extracellular noradrenaline in these neurons by stimulating the LC, or by pharmacological means, inhibited spontaneous activity while preserve or enhance the evoked response to sensory stimulation in auditory, visual and somatosensory pathways (Foote et al., 1975; Moises et al., 1981; Woodward et al., 1979). In some cases, non-responsive neurons could be shifted to a responsive mode by increasing extracellular noradrenaline, a phenomenon that has been referred to as sensory gating (Sara, 2009).

Works in cat (McLean & Waterhouse, 1994) and rat (Waterhouse et al., 1990) primary visual cortex have shown that iontophoretically applied NE can alter specific receptive field properties (e.g., direction selectivity, velocity tuning, response threshold) of visually responsive neurons. Additional NE-induced alterations in the receptive field structure of sensory neurons have been observed for single neurons in somatosensory and auditory cortices (George, 1992; Manunta & Edeline, 1997) and cochlear nuclei (Kossl & Vater, 1989). As such, these results go beyond the demonstration of simple norepinephrine-induced changes in the magnitude of synaptically evoked responses and demonstrate that NE can selectively alter feature extraction properties of individual sensory neurons.

Overall, these findings support the general hypothesis that a major function of the central LC–noradrenergic efferent system is to facilitate the transfer of information through sensory circuits following events that physically activate the LC nucleus.

1.4.3. LC modulation of behaviour and cognition

Previous studies based on lesion and pharmacologic manipulations have indicated roles of the LC-NE system in the sleep-waking cycle (Jouvet, 1969), learning and memory (Crow & Wendlandt 1976; Everitt et al. 1983; Harris & Fitzgerald 1991; Mohammed et al. 1986), certain autonomic functions (Miyawaki et al. 1991, 1993; Ward & Gunn 1976), affective states (Siever & Davis 1985; Valentino and Curtis 1991), and vigilance (Aston-Jones, 1985; Aston-Jones and Bloom 1981a). In particular, pharmacological studies have provided evidence that noradrenaline, interacting with other neuromodulators and hormones, modulates memory formation, mainly through actions in the amygdala and the hippocampus (see Cahill & McGaugh, 1996, for a review). Other pharmacological approaches have revealed a noradrenergic influence in frontal cortical regions that are engaged in attention and working memory functions (reviewed in Robbins & Roberts, 2007; Arnsten & Li, 2005).

LC phasic activation (and more generally the noradrenergic system) was often associated with target detection processes in both monkeys and humans (Aston-Jones & Cohen, 2005; Murphy et al., 2014). In one series of experiments (Aston-Jones et al., 1994; Aston-Jones et al 1999; Rajkowski et al., 2004), LC activity was recorded while monkeys performed a simple detection task in which they were required to release a lever immediately following a specific infrequent visual target (e.g. a vertical bar) to receive a juice reward. Results of these studies showed that LC neurons were physically activated by target stimuli, and only weakly or not at all by distractor stimuli. LC activation did not occur on trials in which the animal made no response despite viewing the cue, and there was no LC response associated with spurious lever responses that occasionally occurred between trials when no stimulus was present. The LC response was also not linked to a specific reward because similar responses are observed for different juice rewards or for water reward in fluid-restricted subjects (Figure 1.40). Recordings during reversal training indicated that these LC responses were not specific to particular sensory attributes of the target but rather to stimulus meaning. Indeed, in these experiments where the distractor becomes the target and vice versa, LC phasic responses quickly became selectively activated by the new targets and extinguished for the new distractors. Also, LC did not respond physically to distractors even if they are infrequent, and LC responses occur even when targets are presented on every trial. This indicated that frequency was not the determining factor for LC activation.

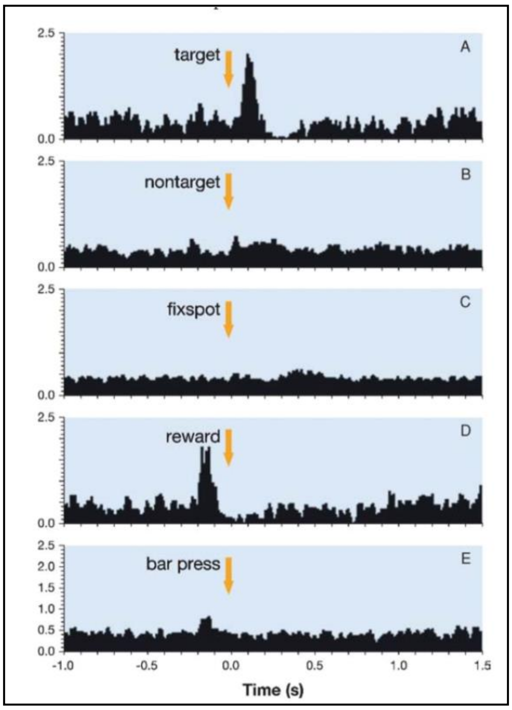

Figure 1.40. Phasic activation of monkey LC neurons in a signal-detection task. Peri-event time histograms (PETHs) for a typical individual LC neuron in response to various events during performance of the signal-detection task. PETHs are each accumulated for 100 sweeps of activity in this neuron synchronized with (*A*) target stimuli, (*B*) non-target stimuli, (*C*) fix spot presentation, (*D*) juice solenoid activation, or (*E*) bar press and release performed outside of the task, as indicated. Note the selective activation following target stimuli (*panel A*). The activation seen before reward presentation (*D*) is due to activation following target cues. From Aston-Jones et al. (1994).

In human studies, the lack of non-invasive measures capable of measure changes in the LC-NA system’s activity did not allow a broad theoretical development of LC-NA function in human about the understanding such as that obtained with animal studies. Pupil diameter has recently emerged as a promising candidate proxy measure for LC activity, and is being increasingly employed for this purpose (Einhauser et al., 2008; Gilzenrat et al., 2010; Jepma & Nieuwenhuis, 2011; Kuipers & Thierry, 2011; Murphy et al., 2011; Nassar et al., 2012; Preuschoff et al., 2011; Smallwood et al., 2011, 2012). Indeed, recent studies have reported that pupil diameter tracks changes in the exploration-exploitation trade-off (Gilzenrat et al., 2010; Jepma & Nieuwenhuis, 2011) and the uncertainty associated with incoming task-relevant information (Nassar et al., 2012;

Preuschoff et al., 2011) in ways that are generally consistent with prominent accounts of LC-NA function (Aston-Jones & Cohen, 2005; Yu & Dayan, 2005).

Murphy and colleagues (2014) used simultaneous pupillometry and blood-oxygen-level-dependent (BOLD) functional magnetic resonance imaging (fMRI) to investigate the relationship between fluctuations in pupil diameter and human LC activity, both at rest and during performance of the classical simple detection task paradigm. Their results showed a positive correlation between pupil diameter and BOLD activity in the rostral LC, as localized via both neuromelanin-sensitive structural imaging (Shibata et al., 2006) and a previously published LC atlas (Keren et al., 2009). They found for the first time a direct functional connection between LC neurons and the pupil diameter modifications. More important for our purpose, the region of overlap between the LC atlas (Keren et al., 2009) and the dorsal pontine cluster that correlated with pupil diameter during task performance exhibited a greater evoked response to target stimuli than to standards. In addition, between-subject's correlations revealed that larger target-evoked BOLD responses within this VOI were robustly associated with faster mean response times (RTs) across subjects. This observation constitutes the first demonstration in humans of a cardinal characteristic of animal LC activity: phasic modulation by stimulus-relevance on the oddball task (Aston-Jones et al., 1994; Rajkowski et al., 1994, 2004).

All together, these findings indicated that the LC response is highly plastic and that it is not rigidly linked to specific sensory attributes of a stimulus but rather responds to events in a task-sensitive manner. These observations led several investigators to suggest that the LC noradrenaline system facilitates attentional and cognitive shifts and behavioural adaptation to changes in environmental imperatives (Sara & Segal, 1991; Yu & Dayan, 2005; Bouret & Sara, 2005; Bouret & Sara, 2004; Devauges & Sara, 1990).

In this light, Aston-Jones and Cohen (2005) suggested that the LC noradrenaline system "...facilitates behavioural responses to the outcome of task-specific decision processes". The latencies of LC responses to targets were relatively short (100 msec onset), and preceded behavioural responses by 200 msec. The conduction latency for monkey LC impulses to reach the frontal cortex is ~60–70 ms (Aston-Jones et al. 1985), making it possible for NE release to occur at about the time that neural activity in motor cortex associated with the behavioural response begins to develop (about 150 ms before the manual response; Mountcastle et al. 1972). Consistent with this possibility, the latencies of response for LC neurons and lever releases were significantly correlated over trials, so that shorter LC responses were associated with shorter behavioural responses to the same cues. These findings indicate that LC target responses might facilitate behavioural responses to target stimuli. Furthermore, LC phasic response appeared to be closely coupled with the behavioural response more than the presentation of the stimulus. These observations have been confirmed in a signal-detection task in which trial difficulty was manipulated to produce variable RTs. Once again, LC phasic activity was more tightly linked to the RT than to the sensory stimulus and preceded lever responses by ~200 ms (Rajkowski et al. 2004). The pattern of results just described, precludes the possibility that LC phasic activation is driven strictly by stimulus onset, response generation, or reward. Aston-Jones & Cohen (2005) hypothesized that LC phasic activity is driven by the outcome of internal decision processes that may vary in duration from trial to trial (accounting for RT variability) but precede response generation with a regular latency.

As the phasic LC response occurs only for identification of a task-relevant stimulus, and not task-irrelevant stimuli, Aston-Jones & Cohen (2005) proposed the *Adaptive Gain Theory of locus coeruleus–norepinephrine (LC–NE)* function, where they characterize the phasic response of LC neurons as a temporal attentional filter. This theory suggests that once a task-relevant event has been detected, LC neurons fire to increase the sensitivity (or gain) of target neurons, leading to a transient increase in perceptual processing. In their hypothesis, this attentional filter is temporally specific but, given the broad projections of LC neurons, spatially global. In addition, the link to decision outcome, rather than to stimulus presentation, indicates that this LC response primarily modulates specific behaviours rather than sensory processing. Therefore, Aston-Jones & Cohen (2005) proposed that the LC phasic response provides a temporal attentional filter that selectively facilitates task-relevant behaviors. In addition, a theory of event perception suggests that changes in observed activities trigger additional perceptual processing, updating internal representations of the current event (Zacks et al., 2007). These theories suggest that increasing attention in response to task-relevant changes in events may facilitate cognitive processing at the moment of the change (facilitation hypothesis). They further suggest that this facilitation may result from orienting attention to the moment in time that the change occurred, perhaps through the opening of an attentional gate (Olivers & Meeter, 2008).

1.4.4. A possible role for the Dopaminergic system

Besides the noradrenergic Locus Coeruleus (LC), other brainstem neuromodulatory systems include the serotonergic dorsal Raphe nucleus (DR), midbrain dopaminergic neurons of the ventral tegmental area (VTA) and the substantia nigra pars compacta (SNc). Through their widespread projections they influence many brain regions and functions, and have a significant impact on arousal, vigilance, mood and cognition. Moreover, they have multiple reciprocal connections, so it is highly probable that these systems interact with each other. The LC has strong projections to all of the others and receives direct input from its neighbour lateral dorsal tegmental nucleus (LDT) and pedunculo-pontine nucleus (PPN), and from dorsal Raphe nucleus (DR). The DR also projects to ventral tegmental area (VTA) and nucleus basalis of Meynert (NBM), thereby influencing both dopamine (DA) and cholinergic input to the cortex (Hervé et al., 1987). To add to the complexity of the situation, these systems interact at the level of axon terminals by reciprocal modulation of release of transmitters (Pan et al., 2004; Rao et al., 2003). Serotonergic and noradrenergic innervation have similar density and distribution and are extremely wide- spread and largely overlapped (Foote & Morrison, 1987). Moreover, a recent review has emphasized that serotonin and noradrenaline have similar effects on sensory neurons of all modalities, particularly in altering their receptive field properties (Hurley et al., 2004). Cholinergic neurons also have widespread forebrain projections, but with less axonal co-lateralization innervating restricted cortical fields, suggesting a more limited range of influence (Walker et al., 1985).

Dopamine neurons densely innervate the striatum and the frontal cortex, and there are some dopaminergic terminals in the perirhinal cortex and the hippocampus (Gasbarri et al., 1994). It has been suggested that the small amount of dopamine that has been detected in other cortical areas by microdialysis studies, is released from LC terminals (Devoto & Flore, 2006). Accumulating evidence suggests that NE neurons originating from LC innervate the DA neurons of the Ventral Tegmental Area (VTA) and influence VTA-DA neural activity (Park et al., 2017) (Figure 1.41). Moreover, there are striking similarities between the factors that govern the activity of dopaminergic and noradrenergic neurons, suggesting that dopamine and noradrenaline are released simultaneously. For example, both are responsive to motivationally salient events (e.g., reward predictors), and disturbances of both have been implicated in highly overlapping sets of clinical disorders (such as schizophrenia, depression, and attention deficit disorder; Meisenzahl et al., 2007; Chamberlain & Robbins, 2013; del Campo et al., 2013). The effects of these neurotransmitters on target neurons can also be similar (e.g., modulation of gain; Nicola et al. 2000; Servan-Schreiber et al. 1990; Waterhouse et al. 1980, 1984), so differences in the functional roles of the two systems are likely to lie in the anatomical organization of their projection regions, where there are important divergences (Dahlstrom and Fuxe, 1964). The two systems may, however, work in concert in the regions of common projection.

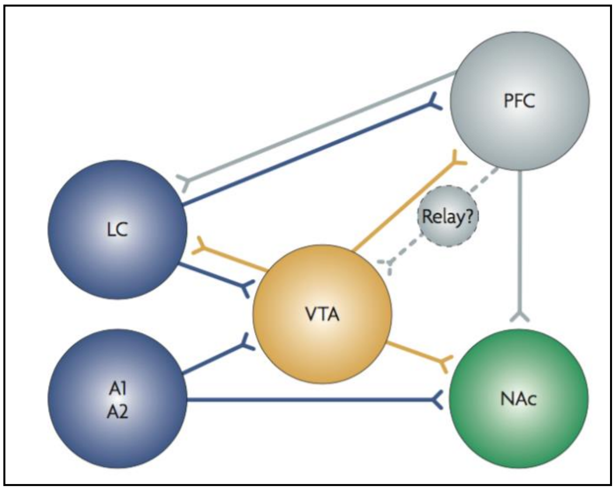

Figure 1.41. Anatomical connections that underlie interactions between the noradrenergic and dopaminergic systems. LC activation elicits burst firing in the VTA, resulting in dopamine release in the nucleus accumbens (NAc). LC activation also affects neurons in the prefrontal cortex (PFC) that project indirectly to the VTA (relay). Release of glutamate in the VTA results in increased excitability and more dopamine release in the NAc. The VTA projects to the LC (Ornstein et al., 1987), as does the PFC (Sara & Hervé-Minvielle, 1995) - A1 and A2 are brainstem noradrenergic cell groups. Termini shown in blue release noradrenaline; termini shown in grey release glutamate; termini shown in yellow release dopamine. Figure from Sara (2009).

On the cognitive point of view, both DA and NE systems are involved in the attentional functions. Ample evidence suggest that dopamine is implicated in attention regulation, and dopaminergic mechanisms may link salience/ reward and attention (Nieoullon, 2002). For example, drugs enhancing dopaminergic transmission facilitate visual attention and memory via the modulation of the dorsal fronto-parietal attentional network (Muller et al., 2005; Tomasi et al., 2011), which is responsible for enhancing salient and attenuating irrelevant stimuli (Corbetta & Shulman, 2002). Dopamine may play a vital role in the balanced and adaptive activation of functionally separated attentional networks of alerting, orienting and executive functions (Dang et al., 2012). Dopaminergic signals in the striatum and its interaction with the prefrontal cortex would be especially critical in the regulation and integration of higher-level processes, such as attention and cognitive control (Cools, 2011). Aston-Jones & Cohen (2005), within the Adaptive Gain Theory, proposed that functions of the LC-NE and DA systems may interact synergistically to implement an auto-annealing reinforcement learning mechanism that is adaptive both to the needs of the organism and changes in the environment. Early in learning, when utility is low, LC remains in the tonic mode, favouring exploration. However, as sources of reward are discovered DA-dependent reinforcement learning strengthens behaviours that produce these rewards. This strengthening increases current utility, driving LC into the phasic mode, which further stabilizes and exploits the utility associated with DA-reinforced behaviours. This process continues until the current source of reward is either no longer valued or available. As utility declines, LC is driven back into the tonic mode, promoting exploration and learning of new behaviours.

Turning to the ABE, considering the link between the LC and DA systems, it is possible that the boost effect is mediated by other neurotransmitters beyond the norepinephrine, as the dopamine. Kéri et al. (2013) investigated the Attentional Boost Effect (ABE) using the short-term paradigm in patients with Parkinson's disease (PD). Parkinson's disease (PD) is characterized by the degeneration of dopaminergic neurons in the mesencephalon, resulting in various deficits in motor control, motivation and reinforcement learning, which is modulated by dopamine replacement therapy (dopamine precursor L-3,4-dihydroxyphenylalanine (L-DOPA) and dopamine receptor agonists; reviewed in Frank, 2005; Cools, 2006; Foerde & Shohamy, 2011).

In their first experiment, the authors recruited a group of newly diagnosed, drug-naive PD patients, evaluated before and after the administration of dopaminergic medications (12-week follow-up period). At baseline, in the recognition test (Figure 1.42) PD patients showed an intact Attentional Boost Effect (ABE). Moreover, they were able to recognize target-associated scenes similarly to controls. At follow-up, patients with PD outperformed controls for both target- and distractor-associated scenes, but not when scenes were presented without letters.

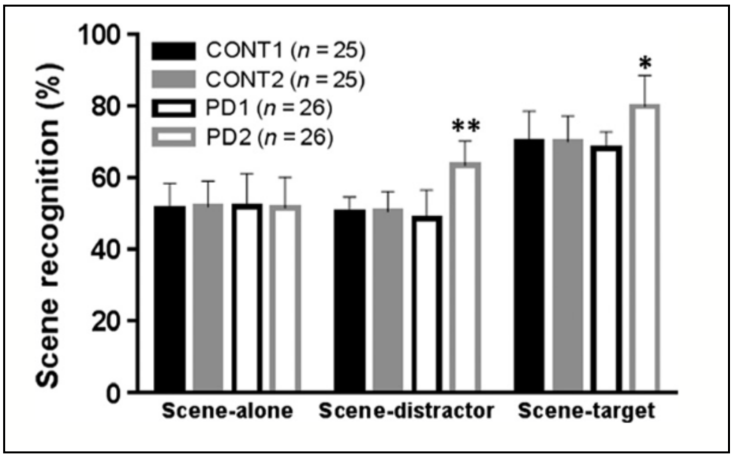

Figure 1.42. Recognition performance for scenes presented alone, with distractor letters, and with target letters in Parkinson's disease (PD) and healthy control individuals (CONT) at baseline (1) and follow-up (2). At follow-up, patients with PD receiving dopamine agonists outperformed control individuals for scenes with targets and scenes with distractors. Error bars indicate SDs.

The authors replicated this enhanced attentional boost in a smaller group of patients with PD receiving L-3,4-dihydroxyphenylalanine (L-DOPA). As before, patients with PD and control individuals performed similarly on the letter detection task. In the recognition test, patients with PD showed higher levels of scene recognition than control individuals when scenes were presented with targets and distractors in the trial sequence (Figure 1.43).

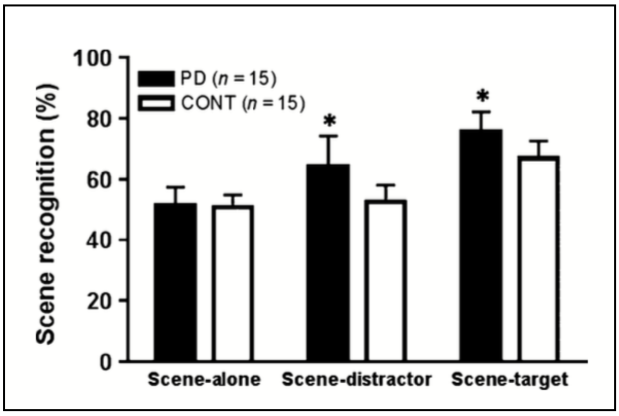

Figure 1.43. Recognition performance for scenes presented alone, with distractor letters, and with target letters in Parkinson's disease (PD) receiving L-3, 4-dihydroxyphenylalanine (L-DOPA) and healthy control individuals (CONT). Patients with PD outperformed controls for scenes with targets and distractors (*P < 0.01, Tukey HSD test).

These results seemed to indicate that dopamine facilitated memory for information presented with both targets and distractors. Furthermore, dopamine agonists and L-DOPA had no general enhancing effect on memory because recognition memory for scenes presented alone was not encouraged. The authors found that higher impulsive attention, measured by the Barratt Impulsiveness Scale-11 (BIS-11; Patton et al., 1995) was associated only with better scene recognition performance when scenes were presented with distractors in the encoding phase. This finding is against the hypothesis that dopamine selectively enhances memory for target-associated background information. It is possible that PD patients encoded scenes not only at behaviourally rewarded points of time (maybe thanks to the noradrenergic phasic activation), but also at behaviourally inhibited occasions when central stimuli (distractors) had to be ignored. In the letter detection task, PD patients and controls at baseline and follow-up showed similar performances. It means that they successfully ignored distractors in the detection task. However, compared to controls, PD patients had increased levels of recognition for scenes exposed concurrently with the omitted distractors, suggesting that they failed to ‘close the window of attention’ spreading to the background scene. In a different paradigm, Cools et al. (2010) also revealed that dopaminergic medications decreased ‘distractor resistance’ in PD (see also Moustafa et al., 2008).

2. Experimental chapter

2.1. Aim of the thesis

Traditionally, memory studies show that dividing attention between two tasks in the encoding phase impairs the performance in a later explicit test such as recognition, cued recall and free recall (Baddeley, Lewis, Eldridge, & Thomson, 1984; Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; Mulligan, 1998; 2008). The Attentional Boost Effect is a particular phenomenon where the division of the attention during the encoding phase in a dual task paradigm does not impair but improves the performance in a later memory test (Swallow & Jiang, 2010). The authors demonstrated that pictures, that participants had to memorize, presented with a target, a stimulus that require a response, during the encoding phase were better recognized in the test phase than pictures encoded with a distractor. Swallow & Jiang (2010) hypothesize that the detection of the target in the secondary task induces a transient attentional response when the target appears. This attention orientation response leads to an increase in the attentional resources available, facilitating the processing and the encoding of the both primary and secondary stimuli (the picture and the square) into the memory. The suggested that this mechanism was based on a transient increase in the release of the norepinephrine from the locus coeruleus – a small nucleus in the brainstem which has widespread connections with many cortical regions, including the hippocampus and the occipital cortex. According to their interpretation, the ABE represents a dynamic trade-off between an *attentional competition*, that is an interference effect on the memory task due to the increase in the demand for the attentional resources needed to monitor the colour of the squares in detection task, and an *attentional boost*, that is a facilitation effect on the memory task due to the transient increase in attention thanks to the target detection in the secondary task. When the facilitation dominates it is possible to observe the ABE; when prevails the attentional competition the ABE is eliminated.

Starting from these theoretical framework, this thesis had two parallel aims.

A first aim was to extend the behavioural results, investigating the presence of the boost effect in specific populations, healthy older adults and euthymic bipolar patients. To do this, we used the last paradigm by Swallow & Jiang (2014, see paragraph 1.1.2.1). We presented a series of pictures with a square in the centre that could be red (the target condition), or more often green (the distractor condition). Some trials were presented with no squares, defining the baseline condition.

The instructions were to pay attention to the pictures (incidental instruction) and at the same time press as quickly as possible the spacebar every time the red squares appeared. After a 15 minute-interval, an old-new recognition task examining memory for the encoded pictures was administered to all participants. In the experimental chapter on older adults (chapter 2.2) we introduced some manipulations to investigate more deeply the limits of the ABE in these subjects, changing the type of material in the memory task (using words in Exp. 2), the instructions (using intentional instruction in Exp. 3) and the stimulus presentation time (using a longer presentation in Exp. 4) in the encoding phase. Both healthy aging and bipolar disease, even in a remission phase, are characterized by the presence of cognitive deficits, in particular by a memory and an attention decline (Balota, Dolan & Duchek, 2000; Glisky, 2007). In agreement with the interpretation of the ABE as a dynamic trade-off between an attentional competition and an attentional boost, any increase in the attentional requirements of the detection task should result in an impairment in the encoding of target-associated stimuli, and thus a reduction, or even a complete elimination, of the memory facilitation produced by the ABE. In agreement, Swallow & Jiang (2010, Exp.5, see paragraph 1.1.2) showed that enhancing the difficulty of the detection task by requesting different responses to different target items was sufficient to cancel the ABE in younger adults. According to this *attentional hypothesis*, we predicted that the temporal constrains of the detection task leads older adults and bipolar patients to devote more attentional resources to this task, at expanses of the memory task. Then, we should have observed a worst performance of older adults and patents on the target condition compared to the younger adults. A possible alternative hypothesis was discussed. Several studies (Hasher & Zacks, 1988; Hartman & Hasher, 1991; Zacks, Radvansky & Hasher, 1996) showed that an inhibition deficit could be present in these populations. Indeed, these subjects showed difficulties to inhibit the processing of irrelevant information (Conelly, Hasher & Zacks, 1991; Carlson et al., 1995). The last paradigm by Swallow & Jiang (2014), according their explanation, allowed to highlight the action of two process: a facilitation mechanism, due to target detection, and an inhibitory mechanism, due to distractor rejection. The authors performed four experiments to investigate if the ABE was generated by a target-induced enhancement (*enhancement hypothesis*) or by a distractor-induced inhibition (*inhibition hypothesis*), or a combination of them (see paragraph 1.1.2.1). Comparing the target and the distractor conditions with the results obtained in a baseline condition (where stimuli were presented with no squares, then neither of the two processes acted), it was possible to observe: the advantage of the target condition compared to the baseline condition, reflection the influence of the facilitatory processes due to the target detection on memory; no differences between the distractor and the baseline conditions, reflecting the absence of the influence of the inhibitory processes due to the distractor rejection in determining the presence of the ABE. Based on this interpretation of this paradigm, and on the evidence indicating an inhibitory deficit in healthy aging and bipolar disease in a remission phase, we discussed an alternative hypothesis, the *inhibition deficit hypothesis*. According to this hypothesis, the advantage of the target condition should be eliminated by the selective increase of the accuracy in the distractor condition. If this were the case, we expected a better recognition of the stimuli presented with distractors compared to the stimuli presented with no squares (in the baseline condition). In conclusion, we expected the elimination or a strong reduction of the ABE in the older and bipolar participants, with different pattern of results depending on the hypothesis.

A second purpose of this thesis was to investigate the neural basis of the ABE by recording the performance of healthy young subjects during the acquisition of functional magnetic resonance images. We adapted the first paradigm used by Swallow & Jiang (2010, 2011), using the same frequency of presentation of targets and distractors. More specific, we selected a series of pictures from two relevant semantic categories, pictures containing a person and pictures containing a building. Half of the pictures at encoding was presented with the red target square, the other half was presented with the green distractor square. The instructions were to memorize the pictures (intentional instruction) and at the same time press as quickly as possible the spacebar every time the red squares appeared. After 15 minutes' interval, participants performed an old/new recognition task. In this experiment we wanted to verify the involvement of the attentional network and of primary auditory cortex in the ABE, replicating the results obtained by Swallow et al. (2012) with stronger behavioural results. In particular, we expected a significantly bigger activation of this regions in the target condition. Moreover, we assessed the influence of the category salience of the pictures on the effect, according to the *early-phase-elevated-attention hypothesis* of the ABE (Mulligan & Spataro, 2015). Previous results suggested that the target detection should enhance processes of stimulus perception and comprehension occurring in the early phases of memory encoding, without involving interpretive elaboration and mental imagery processes occurring in the late phases of encoding (Mulligan & Spataro, 2015). Several works demonstrated that the ABE was absent for stimuli with distinctive and salient features, suggesting that the effect was not mediated by distinctiveness and perceptual saliency (Swallow & Jiang, 2010; Mulligan et al., 2014; Spataro, Mulligan & Rossi-Arnaud, 2015). Because persons are stimuli particularly salient for us and processes in an automatic manner (Thorpe, Fize, & Marlot, 1996; Tanaka & Gauthier, 1997; Li et al., 2002), we hypothesized a better memory performance for scene containing person but to observe the ABE only for scenes containing building. Indeed, scenes with person should attract automatically attention because of their saliency, and this effect should be redundant with the mechanism underlying the boost effect.

2.2. The Attentional Boost Effect is eliminated in young-old adults

2.2.1. Introduction

The Attentional Boost Effect (ABE) represents a counterintuitive phenomenon in which divided attention (DA) at encoding produces a robust advantage in a later memory task (Swallow & Jiang, 2010; see Swallow & Jiang, 2013, for a review). This is at odds with most previous results reported in literature, in which DA during the study phase typically impaired memory performance (Baddeley, Lewis, Eldridge, & Thomson, 1984; Craik, Govoni, Naveh-Benjamin, & Anderson, 1996). Importantly, the ABE has been thus far examined only in young adults. Thus, the question of whether DA continues to facilitate explicit memory in the healthy aged population has yet to be assessed. The present set of four experiments was aimed at filling this gap, by comparing the ABE of younger and older adults in a variety of experimental conditions, which differed for the nature of the stimuli (images vs. words), the duration of the encoding trials (500 vs. 1000 ms) and the type of study-phase instructions provided to participants (incidental vs. intentional).

In the latest version of the ABE paradigm, participants were presented with a long sequence of faces flanked by two target squares (e.g., orange), two distractor squares (e.g., blue) or no squares – the latter condition representing the baseline (Swallow & Jiang, 2014). The instructions were to study the faces and simultaneously press the spacebar when the target squares appeared on the screen (no action was required in response to the distractor squares). When memory for the faces was later probed in a recognition task, the results showed that the performance was significantly better for the faces encoded in the target condition than for the faces encoded in the distractor or no-square conditions, which did not differ between them. While Swallow and Jiang (2010, 2011, 2012, 2014) examined the recognition of visual stimuli (see also Rossi-Arnaud, Spataro, Costanzi, Saraulli, & Cestari, 2017), other studies have extended the ABE to the retrieval of verbal material (words), in both explicit and implicit memory tasks (Mulligan, Spataro, & Picklesimer, 2014; Spataro, Mulligan, & Rossi-Arnaud, 2013, 2015).

To account for their findings, Swallow and Jiang (2013) proposed the so-called *dual-task interaction model*. This framework assumes that, on each trial, information from the squares and the background images (or words) compete for representation in the primary visual cortex, producing dual-task interference (Swallow, Makovski, & Jiang, 2012). In addition, interference would also result from the need to maintain two simultaneous goals in working memory – encoding the background stimuli and responding to the target squares. To resolve this competition, a cognitive control system like the central executive prioritizes the elaboration of the goal-relevant items (i.e., the to-be-responded squares). The rapid categorization of target squares as stimuli that require an overt response triggers *temporal selective attention* (Olivers & Meeter, 2008), a mechanism which in turn enhances the perceptual processing of all information presented at the same time as targets. The authors hypothesized that this mechanism is based on a transient increase in the release of norepinephrine from the locus coeruleus – a nucleus in the brainstem which has widespread connections with many cortical regions, including the hippocampus and the occipital cortices (Aston-Jones & Cohen, 2005; Nieuwenhuis, Gilzenrat, Holmes, & Cohen, 2005). The dual-task interaction model makes it clear that the ABE represents a dynamic trade-off between *attentional competition* and *attentional boost*, with the latter dominating under specific circumstances (Spataro et al., 2013; Swallow & Jiang, 2010). In support of this claim, Swallow and Jiang (2010, Exp.5) reported that a modest increase in attentional competition during the target detection task was sufficient to eliminate the ABE. They contrasted a standard condition involving a simple-detection task with a second condition involving an arbitrary-mapping task. In both cases, the targets were red or green squares, and the distractors were black squares. Importantly, distinct types of responses were required in the two conditions: in the simple-detection task participants pressed the spacebar every time that a red or a green square appeared on the screen, whereas in the arbitrary-mapping task they pressed one key for red squares and another key for green squares. The results of a later recognition task showed that the ABE was significant in the simple-detection condition, whereas it was abolished in the arbitrary-mapping condition. Swallow and Jiang (2010) concluded that, in the latter condition, the facilitation produced by the attentional boost was offset by the additional attentional processes required by target detection (such as accessing the response mapping in working memory and selecting an arbitrary response).

Evidence from numerous studies suggest that ageing entails both cerebral and cognitive changes. For example, structural alterations in grey (see Raz, 2000, for a review) and white matter (Sullivan & Pfefferbaum, 2006) are commonly reported in older adults. Likewise, functional neuroimaging studies have shown different patterns of activation in a variety of cognitive and memory tasks: here, the typical finding is that older adults activate some brain areas in common with younger adults, although often to a lesser degree; in addition, they also recruit regions that are not activated in the younger group, suggesting the use of compensatory mechanisms (Grady, 2000; Logan, Sanders, Snyder, Morris, & Buckner, 2002; Spreng, Wojtowicz, & Grady, 2010). Most important for our purposes, dozens of studies have reported that cognitive and memory abilities decline with age (Craik & Jennings, 1992). In the literature, episodic memory deficits are frequently observed in healthy adults, especially in dual-task conditions (Grady & Craik, 2000), and different hypotheses have been put forward to explain this decrement. One relevant account is the *reduced attentional resources hypothesis*, which suggests that an age-related loss of attention resources would impair, in older adults, the ability to perform two simultaneous tasks with the same accuracy observed in younger adults (Craik & Byrd, 1982; Rabinowitz, Craik & Ackerman, 1982). Although this idea has been criticized by a series of studies showing that healthy older participants are able to process two tasks in parallel if one or both of them are based on highly automatic processes (Allen et al., 2002; Allen, Lien, & Jardin, 2017; ; Hartley, Seaman, & Maquestiaux, 2015; Lien, Allen, Ruthruff, Grabbe, & McCann, 2006), it has continued to provide a fruitful theoretical framework for understanding a wide variety of empirical findings (see Kilb & Naveh-Benjamin, 2015, for a review). In particular, a set of classical experiments using the DA paradigm have consistently demonstrated that the attentional demands of explicit encoding processes are significantly higher in older than in younger adults (Anderson, Craik, & Naveh-Benjamin, 1998; Anderson et al., 2000; Castel & Craik, 2003; Naveh-Benjamin, Craik, Guez, & Kreuger, 2005). Anderson and colleagues (1998), in particular, examined the effects of study-phase DA on free recall, cued recall and recognition. Younger and older participants intentionally studied lists of words presented in the auditory modality while simultaneously performing a four-choice continuous reaction time (RT) task in which they had to detect a target (a white box) appearing in one of four quadrants of the computer screen. The results revealed that DA at encoding impaired memory performance equally for the two age groups; however, secondary task RTs were slowed to a greater extent in older than in younger adults, especially when the instructions emphasized accuracy in the memory test. These results suggest that older people can reach a memory performance comparable to that obtained by younger adults, but this implies higher costs in terms of attentional resources.

Turning to the ABE paradigm, we predicted that the temporal constraints of the secondary task (in which the to-be-responded squares are presented for only 100 ms) might lead older adults to devote more attention resources to the detection of target squares, at the expenses of the memory task. That is, we anticipated that detection tasks like those used in the ABE paradigm may become increasingly difficult in older adults: according to *reduced attentional resources hypothesis*, this should reduce the amount of resources allocated to the encoding of target-associated stimuli, resulting in the elimination (or a strong reduction) of the memory facilitation produced by the ABE. Under standard conditions, in which both tasks are emphasized to the same degree, the enhanced difficulty of the secondary task should manifest itself as longer RTs or a lower accuracy in the detection of target squares in the older group (as reported by Anderson et al., 1998). However, in our previous studies on the ABE (and in the first two experiments of the present study), we used incidental instructions, such that participants were not explicitly required to encode the background stimuli into memory and were unaware of the following recognition test. It seems likely to suggest that, in the latter conditions, older adults would emphasize the fast and accurate detection of target squares more than the encoding of the background stimuli (see Meyer & Kieras, 1997, for an example of a theory in which resources can be strategically allocated across two or more tasks). In agreement, a number of electrophysiological studies have documented that cognitively high-performing older adults can achieve RTs and accuracy rates equivalent to those reached by younger adults in simple detection tasks. Daffner et al. (2005, 2006), for instance, compared the performance of old, middle-aged and young participants in a visual novelty oddball task, while recording event-potentials. The results showed no differences across age groups in overall RTs and percent correct hits to target stimuli, or in percent false alarms to distractor stimuli. However, old adults had larger, more anteriorly distributed P300 components to all types of stimuli, suggesting that, compared to young participants, they managed the task by recruiting additional (compensatory) neural resources and more effortful frontal processes. Therefore, even in the absence of behavioral deficits, the increased attentional resources required by the detection task should be sufficient to impair the encoding of target-associated stimuli, thus reducing (or eliminating) the ABE.

The *reduced attentional resources hypothesis* attributes the absence of the ABE to an age-related deficit in the elaboration of the background images (or words) paired with target squares. However, other researchers have proposed that different mechanisms underlie the episodic memory difficulties experienced by older adults: these alternative explanations led to the same general prediction (that the ABE should be eliminated in the older group), but for different reasons. More specifically, the *inhibition deficit hypothesis* (Hasher & Zacks, 1988) suggests that aging reduces the ability to inhibit distractor processing (de Fockert, Ramchurn, Van Velzen, Bergström, & Bunce, 2009; Haring et al., 2013; Hasher, Zacks, & May, 1999; Healey, Ngo, & Hasher, 2014). In agreement, in several studies delineating the so-called “hyper-binding” effect, younger and older participants were required to perform a selective attention task on pictures, while ignoring superimposed distractor words; later, older adults outperformed younger adults in both explicit and implicit tasks examining memory for previous distractor words, suggesting less inhibition (i.e., enhanced processing) of these items at encoding (Campbell, Hasher, & Thomas, 2010; Rowe, Valderrama, Hasher, & Lenartowicz, 2006). In the case of the ABE paradigm, this hypothesis predicts that the advantage of target-associated stimuli should be eliminated because of a selective increase in the recognition of distractor-associated stimuli. If this were the case, we should expect distractor-associated stimuli to be recognized significantly better than baseline stimuli.

The present study tested these alternative hypotheses in four experiments which employed either visual (images: Exp.1) or verbal (words: Exp. 2, 3 and 4) materials; furthermore, we also manipulated the nature of the instructions (incidental vs. intentional encoding) and/or the length of the encoding trials (500 vs. 1000 ms).

2.2.2. Experiment 1

Experiment 1 began our investigation by examining the ABE with visual stimuli (images) in younger and older adults. We used the modified version of the ABE paradigm illustrated by Swallow and Jiang (2014), in which the baseline trials were embedded in the DA condition. Of note, instructions for the encoding task were incidental (as in Spataro et al., 2013, 2015), in that participants were not told to memorize the images and they were unaware of the upcoming recognition test. It was anticipated that, in these conditions, older adults should emphasize the detection task more than the memory task: therefore, we expected their performance to resemble that of younger adults in terms of RTs and accuracy rates.

To recap, the reduced attentional resources hypothesis predicts that a significant ABE should be observed in younger adults, but not in older adults; more crucially, the elimination of the ABE should be the consequence of an age-related deficit in the encoding of target-associated images (or words): thus, the recognition of these stimuli should be significantly lower in the older than in the younger group. On the other hand, the inhibition deficit hypothesis predicts that the ABE should be reduced in older adults because they have a specific deficit in the inhibition of distractor-associated stimuli: in other words, this account suggests that distractor stimuli should be recognized with the same accuracy as target stimuli, and both stimuli should be recognized better than baseline stimuli.

2.2.2.1. Materials & Method

2.2.2.1.1. *Participants*

Twenty-four healthy young-old adults between 60 and 75 years (14 females; mean age = 66.04 years) volunteered to participate. Twenty-four students of the University Sapienza of Rome, from 18 to 35 years old, served as controls (18 females; mean age = 23.71 years). All participants had normal or corrected-to-normal vision, and reported to be in good health (no neurological or psychiatric diseases). Four subtests of the WAIS-IV (Wechsler, 2013; Orsini & Pezzuti, 2013) were administered to all participants – Digit span (forward and backward) and Arithmetic to evaluate working memory, and Symbol Search and Digit Symbol-Coding to evaluate processing speed (see Table 2.1 for means and *t*-test statistics). Education was greater for younger (M = 15.7) than for older adults (M = 13.3), $t(46) = 2.96$, $p = 0.005$. Furthermore, younger adults performed better than older adults in the Digit Span subtest [$t(46) = 4.03$, $p < 0.001$ for Digit Span forward and $t(46) = 5.14$, $p < 0.001$ for Digit span backward], and in the processing speed subtests [$t(46) = 6.23$, $p < 0.001$ for Symbol Search and $t(46) = 8.19$, $p < 0.001$ for Digit Symbol-Coding]. In both the present and the following experiments, we chose not to correct statistical analyses for education, because the resulting ANCOVA would violate the assumption that the experimental groups should not differ on the covariate (see Miller & Chapman, 2001, for a discussion about the misuses of ANCOVA). We will return on this issue later, when presenting the Combined Analysis.

Measures	**Experiment 1**		
	Younger	Older	t-test
Age (years)	23.7 (2.7)	66.0 (4.4)	-39.57***
Education (years)	15.7 (1.5)	13.3 (3.6)	2.96*
Digit Span (forward)	10.4 (1.8)	8.4 (1.5)	4.03***
Digit Span (backward)	10.3 (1.8)	7.3 (2.1)	5.14***
Arithmetic	14.3 (2.3)	15.1 (2.7)	-1.17
Symbol Search	38.0 (8.3)	24.1 (7.1)	6.23***
Digit Symbol-Coding	81.1 (14.1)	50.1 (11.9)	8.19***

Table 2.1. Mean scores and *t*-tests for the demographic and cognitive measures of younger and older adults in Experiments 1. Standard deviations are reported in parenthesis. For the WAIS-IV subtests, raw scores are reported. *: $p < 0.05$; ***: $p < 0.001$.

2.2.2.1.2. Materials

A critical set of 45 neutral pictures were selected from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008) – valence: $M = 5.28$, on a 9-point Likert scale ranging from *1 = unhappy* to *9 = very happy*; arousal: $M = 3.18$, on a 9-point Likert scale ranging from *1 = relaxed* to *9 = excited*. This initial set was further divided in three subgroups of 15 images. Each image could be associated to a red square (target condition), a green square (distractor condition) or presented on its own, without squares (baseline condition). The use of the three subsets of images in the different encoding conditions was counterbalanced across participants. An additional set of 124 non-critical neutral images were also selected from the IAPS, to be used as practice (5 images) and filler items (74 images) during the encoding phase, or as foils in the recognition task (45 images). Foils were as similar as possible to the critical images in terms of valence (*M* = 5.29) and arousal (*M* = 3.17). All images were preprocessed with Adobe Illustrator CS6 and presented on the 15” monitor of an HP Pavilion notebook using the software SuperLab 4.0 (Cedrus Corporation, San Pedro, CA). Viewing distance was about 50 cm.

2.2.2.1.3. Procedure

The experiment comprised an encoding phase, a 20-min interval and a test phase. In the encoding phase, participants were presented with a total of 124 images, at a rate of 500 ms/picture (no inter-stimulus interval). For target and distractor trials, one image (1024 × 628 pixels) and one square (70 × 70 pixels; red or green, placed at the center of the image) appeared simultaneously on the screen for 100 ms, after which only the image remained visible for an additional 400 ms. For baseline trials, the images were presented for 500 ms, without squares. The entire presentation was divided in 16 continuous blocks of 5 images each (1 practice block plus 15 critical blocks). Each block included 1 target image (presented with a red square), 1 distractor image (presented with a green square), 1 baseline image (presented without squares) and 2 filler images (presented with green squares). Following Mulligan et al. (2014), the target image was always located in the third position, whereas the distractor and baseline images were located either in the first or in the fifth position (the exact position was counterbalanced across blocks). In addition, from 1 to 5 filler images, always presented with green squares, were placed between adjacent blocks to reduce regularity in the appearance of the target squares. Participants were told to pay attention to the images (incidental instructions) and simultaneously press the spacebar whenever they detected a red square.

During the 20-minute interval, participants undertook the four WAIS-IV subtests. Finally, the recognition task involved the presentation of 90 images randomly ordered, comprising 45 old images (presented at encoding: 15 target, 15 distractor and 15 baseline images) and 45 new images (foils). For each image, the instructions were to press the keys “v” or “n” if the participant judged it to be old or new, respectively.

2.2.2.2. Results

At encoding, younger and older adults were found to be equally accurate in the detection of target squares: *M* = 98% in both groups, *t*(46) = 0.33, $p = 0.74$; false alarms (i.e., incorrect responses to non-target, green squares) were infrequent and did not differ between the two groups: *M*(younger adults) = 0.50 vs. *M*(older adults) = 0.46, *t*(46) = 0.24, $p = 0.81$. Mean RTs were numerically, but not significantly, longer for younger (*M* = 292 ms) than for older adults (*M* = 270 ms), *t*(46) = 1.38, $p = 0.17$.

In the recognition test, the proportions of false alarms were significantly greater in the older (*M* = 0.28) than in the younger group (*M* = 0.21), *t*(46) = −1.98, $p = 0.05$. Therefore, the primary analysis was conducted on corrected recognition scores, computed as the difference between hits and false alarms (see Figure 2.1). Note that, in this and the following experiments, the proportions of hits for the stimuli associated to target squares were adjusted by considering only the trials in which participants correctly pressed the spacebar (Rossi-Arnaud et al., 2017; Spataro et al., 2013). Scores were submitted to a 2 (Group: younger vs. older adults) × 3 (Type of Trial: target, distractor and baseline images) mixed ANOVA. The results showed: a) a significant main effect of Group, *F*(1,46) = 5.26, $p = 0.03$, $\eta_p^2 = 0.10$, with younger adults performing better than older adults (*M* = 0.37 vs. *M* = 0.25); b) a marginal effects of Trial Type, *F*(2, 92) = 2.88, $p = 0.06$, $\eta_p^2 = 0.06$; and, most importantly, c) a significant two-way interaction between Group and Trial Type, *F*(2, 92) = 11.51, $p < 0.001$, $\eta_p^2 = 0.20$. A follow-up analysis of simple effects revealed that the effect of Trial Type was significant in younger adults, *F*(2,45) = 9.96, $p < 0.001$, $\eta_p^2 = 0.31$. For this group, the recognition of target images (*M* = 0.48) was more accurate than the recognition of distractor (*M* = 0.29, $p < 0.001$) and baseline (*M* = 0.33, $p = 0.001$) images, which did not differ between them ($p = 0.34$). For older adults, the effect of Trial Type was marginal, *F*(2, 45) = 2.96, $p = 0.06$, $\eta_p^2 = 0.12$; however, in contrast with the pattern typically observed in the ABE paradigm (Swallow & Jiang, 2014), post-hoc comparisons with the Bonferroni adjustment indicated that older adults recognized baseline images (*M* = 0.30) more accurately than target images (*M* = 0.20, $p = 0.02$). When analyzed in the opposite direction, this same interaction indicated that the effect of Group was significant in the target condition, with younger adults (*M* = 0.48) outperforming older adults (*M* = 0.20), *F*(1, 46) = 17.52, $p < 0.001$, $\eta_p^2 = 0.28$; on the other hand, the two groups did not differ in the distractor and baseline conditions, *F*(1, 46) = 0.47, $p = 0.50$, $\eta_p^2 = 0.01$ and *F*(1, 46) = 0.16, $p = 0.63$, $\eta_p^2 = 0.003$.

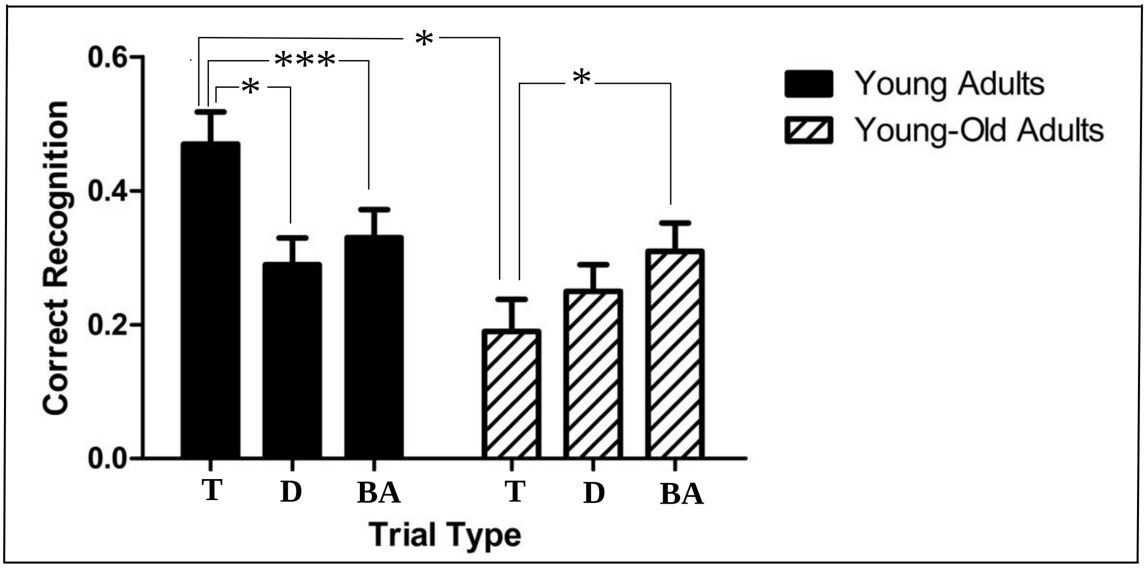

Figure 2.1. Experiment 1 (images encoded for 500 ms, incidental instructions): Mean proportions of Corrected Recognition (hits – false alarms) in young and young-old adults, as a function of Trial Type. Bars represent standard errors. *: *p* < 0.05; ***: *p* < 0.001.

2.2.2.3. Discussion

The results of Experiment 1 were clear in showing that the Attentional Boost Effect (ABE) was significant and robust in size in the group of younger adults (thus replicating previous results: Rossi-Arnaud et al., 2017; Swallow & Jiang, 2010, 2014). On the other hand, the advantage of target over distractor images was completely abolished in older adults, who instead exhibited a decrease in the recognition of the images presented with target squares during the encoding phase (as compared to the younger participants). These findings are consistent with the view that the maintenance of an accurate and fast performance in the detection task recruited more attention resources in older than in younger adults, even in the absence of significant behavioral differences (the two groups showed similar general accuracy and RTs; see Daffner et al., 2005, 2006; Mott et al., 2014). Since these resources were necessarily subtracted from the concurrent memory task, the implication is that responding to the target squares had a more negative impact on image processing in the former than in the latter group. Our current data indicate that this impairment was sufficient to cancel the facilitatory effects produced by target detection on later recognition memory. On the other hand, the data of this first experiment failed to support the inhibition hypothesis (de Fockert et al., 2009; Haring et al., 2013; Hasher et al., 1999; Healey et al., 2014), because older adults did not recognize distractor images better the baseline images; furthermore, there was no evidence that older adults outperformed younger participants in the recognition of the images encoded with distractor squares.

Experiment 2 sought to replicate this pattern of results by investigating the ABE with verbal materials (i.e., words).

2.2.3. Experiment 2

Experiment 2 used the same paradigm illustrated in Experiment 1, with the exception that the images were replaced by words (Mulligan et al., 2014; Spataro et al., 2013, 2015). Besides replicating the findings emerged in Experiment 1, the use of verbal stimuli was justified by previous evidence indicating that, for older adults, the encoding of images might be more attention demanding than the encoding of words. For example, a meta-analysis by Spencer and Raz (1995) found that age differences in explicit memory were larger with visual (objects and pictures: d = 1.07) than with verbal (words: d = 0.57) material (see Leonards, Ibanes, & Giannakopoulus, 2002, for comparable results in working memory). If this was the case, then performing the detection task should produce less negative consequences on the encoding of words. Accordingly, Experiment 2 sought to determine whether a significant ABE could be found when the memory test involved verbal material.

2.2.3.1. Materials & Method

2.2.3.1.1. Participants

Nineteen healthy young-old adults between 60 and 75 years (14 females; mean age = 65.21 years) were recruited to participate in Experiment 2. Nineteen students of the University Sapienza of Rome (13 females; mean age = 28.32 years) served as controls. All participants had normal or corrected-to-normal vision and were in good health (no neurological or psychiatric disorders). The two groups were equated for education, $t(36) = 1.02$, $p = 0.31$. As in Experiment 1, several subtests of the WAIS-IV (Wechsler, 2013; Orsini & Pezzuti, 2013) were administered to both younger and older adults: Digit span (forward and backward) and Arithmetic to evaluate working memory, Symbol Search and Digit Symbol-Coding to evaluate processing speed, and Vocabulary to evaluate verbal knowledge (see Table 2.2). Significant differences between the two groups (favoring younger adults) were obtained in the backward version of the Digit Span subtest, $t(36) = 2.28$, p = 0.03, and in the two processing speed subtests, $t(36) = 3.87$, $p < 0.001$ for Symbol Search and $t(36)$ = 4.01, $p < 0.001$ for Digit Symbol-Coding, respectively.

Measures	Experiment 2		
	Younger	Older	t-test
Age (years)	28.3 (4.9)	65.2 (4.4)	-24.29***
Education (years)	16.4 (2.5)	15.0 (5.5)	1.02
Digit Span (forward)	9.5 (1.9)	9.7 (1.4)	-0.28
Digit Span (backward)	9.0 (1.9)	7.6 (1.6)	2.28*
Arithmetic	14.5 (3.0)	14.6 (3.7)	-0.05
Symbol Search	35.5 (7.6)	26.1 (7.2)	3.87***
Digit Symbol-Coding	71.0 (14.2)	54.1 (10.9)	4.01***
Vocabulary	38.7 (8.8)	36.1 (10.2)	0.83

Table 2.2. Mean scores and *t*-tests for the demographic and cognitive measures of younger and older adults in Experiments 2. Standard deviations are reported in parenthesis. For the WAIS-IV subtests, raw scores are reported. *: $p < 0.05$; ***: $p < 0.001$.

2.2.3.1.2. Materials

A critical set of 45 high-frequency words were selected from the Lexvar database (http://www.istc.cnr.it/it/grouppage/lexvar). We used high-frequency words because a previous study showed that the ABE was strongly reduced with low-frequency words (Mulligan et al., 2014). This initial set was further divided in three sub-lists of 15 words each, matched for frequency [range: 324–330, F (2, 42) = 0.002, p = 1.00] and familiarity [range: 6.38–6.66, F(2,42) = 1.37, p = 0.26]. The use of these sub-lists in the three encoding conditions (target, distractor and baseline trials) was counterbalanced across participants. An additional set of 110 non-critical neutral words were also selected from the Lexvar database, to be used as practice (5 words) and filler items (60 words) during the encoding phase, or as foils in the recognition task (45 words). Foils were as similar as possible to the critical words in terms of frequency (M = 329.31) and familiarity (M = 6.22). As in Experiment 1, all the stimuli were preprocessed with Adobe Illustrator CS6 and presented on the 15” monitor of an HP Pavilion notebook using the software SuperLab 4.0 (Cedrus Corporation, San Pedro, CA). Viewing distance was about 50 cm.

2.2.3.1.3. Procedure

Experiment 2 comprised an encoding phase, a 20-min interval and a test phase. During the encoding phase (modeled after Spataro et al., 2013), participants were presented with a total of 110 words, at a rate of 500 ms/word (no inter-stimulus interval). All words were presented in white against a black background. For target and distractor trials, one word (110 pt; Myriad Pro Semibold font) and one square (70 × 70 pixels; red or green) appeared simultaneously at the center of the screen for 100 ms, with a vertical distance of 1 cm between them, after which only the word remained visible for an additional 400 ms. For baseline trials, only the words were presented for 500 ms, without squares. The entire presentation was divided in 16 blocks (15 critical blocks plus one practice block) of 5 words. Each block comprised: a critical word presented with a red square (target word), a critical word presented with a green square (distractor word), a critical word presented with no squares (baseline word) and two non-critical filler words (always presented with green squares). The arrangement of the items within each block was slightly different from that illustrated in Experiment 1, since each type of word appeared in all available positions an equal number of times (see Rossi-Arnaud et al., 2017, for a similar procedure). The instructions were to read the words aloud (incidental instruction) and press the spacebar every time that a target square appeared on the screen.

During the following 20-min interval, participants completed four of the five subtests of the WAIS-IV (Digit Span, Arithmetic, Symbol Search and Digit Symbol-Coding). Finally, they were administered an old-new recognition test in which 45 old words (15 target, 15 distractor and 15 baseline words) and 45 novel words were randomly presented at the center of the screen. Each word remained on the screen until the participant's response. The instructions were to press the letter "v" if the word was judged to be old (i.e., presented during the encoding phase) or the letter "n" if the word was judged to be new. The Vocabulary subtest of the WAIS-IV was administered at the end of the recognition phase.

2.2.3.2. Results

At encoding, there was a tendency for younger adults (*M* = 100%) to be more accurate than older adults (*M* = 96%) in the detection of the target squares, *t*(36) = 1.96, *p* = 0.07; interestingly, older adults made significantly more false alarms to non-target squares: *M* = 0.63 vs. *M* = 0.00, *t*(36) = -2.58, *p* = 0.02. The mean RTs were comparable across the two groups, being *M* = 265 ms for younger adults and *M* = 266 ms for older adults, *t*(36) = −0.064, *p* = 0.95.

Unlike in Experiment 1, the proportions of false alarms in the recognition tests were numerically, but not significantly, greater in the older (*M* = 0.36) than in the younger (*M* = 0.28) group, t (36) = −1.53, p = 0.13. However, to ensure comparability with the results of Experiment 1, statistical analyses were again conducted on corrected recognition scores (hits – false alarms; see Figure 2.2). A 2 (Group: younger vs. older adults) × 3 (Type of Trial: target, distractor and baseline words) mixed ANOVA revealed a) no significant main effect of Group, $F(1, 36) = 0.33$, $p = 0.57$, $\eta_p^2 = 0.009$, b) a significant main effect of Trial Type, $F(2, 72) = 10.98$, $p < 0.001$, $\eta_p^2 = 0.23$; and c) a significant interaction between Group and Trial Type, $F(2, 72) = 3.03$, $p = 0.05$, $\eta_p^2 = 0.08$. A follow-up analysis of simple effects on the two-way interaction demonstrated that the effect of Trial Type (i.e., the Attentional Boost Effect) was significant in younger adults, $F(2, 35) = 10.52$, $p < 0.001$, $\eta_p^2 = 0.37$. For this group, the recognition of target words ($M = 0.35$) was significantly more accurate than the recognition of distractor ($M = 0.16$, $p < 0.001$) and baseline words ($M = 0.23$, $p = 0.03$), which did not differ between them ($p = 0.10$). In contrast, the effect of Trial Type was absent in older adults, $F(2, 35) = 1.56$, $p = 0.22$, $\eta_p^2 = 0.08$, with no significant difference between the three conditions. Unlike in Experiment 1, this same analysis indicated the effect of Group (i.e., the difference between younger and older adults) was never significant ($p = 0.20$ for target words, $p = 0.41$ for distractor words, and $p = 0.47$ for baseline words), although younger adults continued to show a sizeable numerical advantage in the target condition (see Figure 2.2).

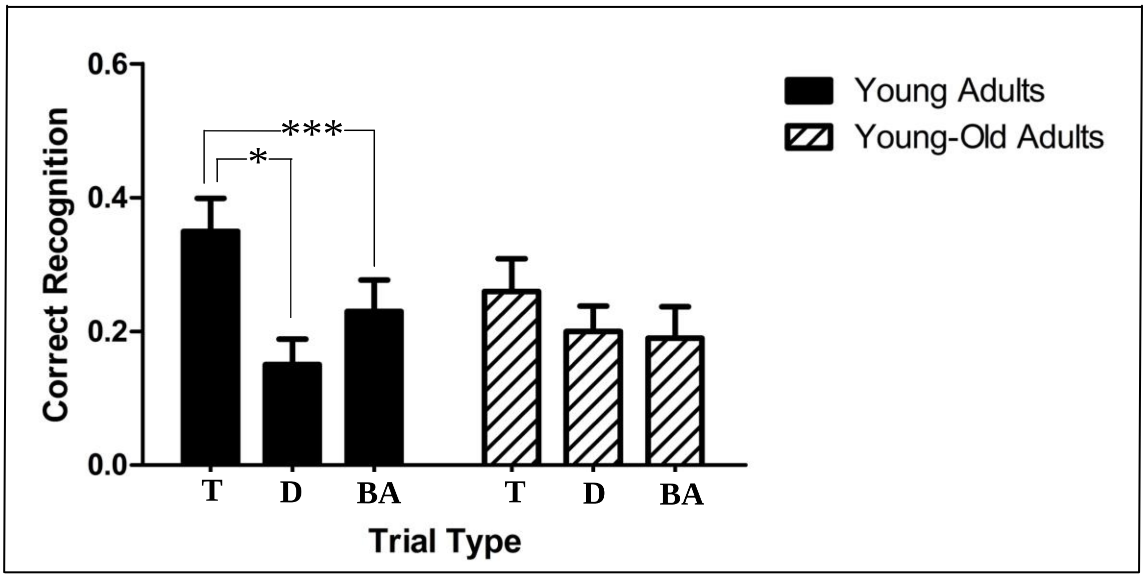

Figure 2.2. Experiment 2 (words encoded for 500 ms, incidental instructions): Mean proportions of Corrected Recognition (hits – false alarms) in young and young-old adults, as a function of Trial Type. Bars represent standard errors. *: $p < 0.05$; ***: $p < 0.001$.

2.2.3.3. Discussion

The results of Experiment 2 were broadly consistent with those obtained in Experiment 1, since the ABE was again robust and significant in the group of younger adults, whereas it was completely abolished in the group of older adults. The two groups showed comparable RTs in the secondary task. However, older adults were slightly less accurate in the detection of target squares (although the difference did not reach the significance level) and exhibited more false alarms to non-target squares. Together with the age-related deficit in the recognition of target stimuli, these findings provide additional support to the hypothesis that the attentional demands of the detection task were higher in older than in younger adults.

At the same time, we must note a minor, but interesting, difference with respect to Experiment 1: namely, the fact that in the group of older adults the recognition of target stimuli was less accurate than the recognition of baseline stimuli in Experiment 1, but not in Experiment 2 (in which the numerical trend actually ran in the opposite direction). As outlined above, this finding might reflect intrinsic differences in the amount of cognitive resources required by the encoding of images and words, with the former being more demanding than the latter. Thus, in older adults, DA at encoding produced more detrimental effects on the recognition of images than on the recognition of words – as also indicated by the fact that younger adults performed better than older adults in the target condition in Experiment 1, but not in Experiment 2.

In the next two experiments, using the ABE paradigm with verbal stimuli, we manipulated the encoding time (Exp. 3) and the nature of the instructions provided to participants during the encoding phase (Exp. 4), in the attempt to allow older adults to allocate more attention resources to the memory task.

2.2.4. Experiment 3

Experiment 3 used the same words and procedures as in Experiment 2, with the exception that the presentation time during the encoding phase was increased to 1000 ms (note that, in previous studies, a significant ABE has been reported when words were presented for 1500 ms: Mulligan & Spataro, 2015; Spataro, Mulligan, Bechi Gabrielli, & Rossi-Arnaud, 2017). As in Experiment 2, the instructions were incidental, meaning that participants were not explicitly told to study the words in view of an upcoming recognition task. Our rationale was that relaxing the temporal constraints associated to the detection task should allow participants to devote more attention resources to the encoding of the background words.

2.2.4.1. Materials & Method

2.2.4.1.1. Participants

Twenty-four healthy young-old adults between 60 and 75 years (15 females; mean age = 68.42 years) volunteered to participate. Twenty-four students of the University Sapienza of Rome, from 18 to 35 years old, served as controls (8 females; mean age = 22.38 years). As reported in Table 2.3, the two groups were equated for education, $t(46) = 1.22$, $p = 0.23$. On the other hand, significant differences between the two groups (favouring younger adults) were obtained in all the WAIS subtests (Wechsler, 2013; Orsini & Pezzuti, 2013): $t(46) = 2.91$, $p = 0.006$ for Digit Span forward, $t(46) = 3.76$, $p < 0.001$ for Digit Span backward, $t(46) = 10.40$, $p < 0.001$ for Symbol Search, $t(46) = 7.49$, $p < 0.001$ for Digit Symbol-Coding, and $t(46) = 3.11$, $p = 0.003$ for Vocabulary. In addition to the WAIS subtests, older adults in Experiments 3 were preliminarily screened for cognitive impairment using the Mini Mental State Examination (MMSE) (Folstein et al., 1975). They all reported scores within the range of normality (i.e., > 24: Magni et al., 1996).

Measures	**Experiment 3**		
	Younger	Older	t-test
Age (years)	22.4 (3.5)	68.4 (6.0)	-32.30 ***
Education (years)	12.9 (2.9)	11.6 (4.0)	1.22
Digit Span (forward)	9.8 (1.9)	8.2 (1.8)	2.91 *
Digit Span (backward)	9.0 (2.0)	7.0 (1.6)	3.76 ***
Symbol Search	35.5 (4.8)	20.3 (5.2)	10.40 ***
Digit Symbol-Coding	72.2 (9.3)	47.3 (13.2)	7.49 ***
Vocabulary	37.5 (7.4)	29.5 (10.0)	3.11 *
MMSE	NA	27.22 (1.87)	NA

Table 2.3. Mean scores and *t*-tests for the demographic and cognitive measures of younger and older adults in Experiments 3. Standard deviations are reported in parenthesis. For the WAIS-IV subtests, raw scores are reported. *: $p < 0.05$; ***: $p < 0.001$.

2.2.4.1.2. *Materials*

The same words used in Experiments 2 were also employed in Experiment 3.

2.2.4.1.3. *Procedure*

The procedure was the same as that illustrated in Experiment 2, with the exception that each encoding trial lasted 1 s. Specifically, for target and distractor trials, one word and one square appeared simultaneously at the center of the screen for 200 ms, after which only the word remained visible for an additional 800 ms. For baseline trials, only the words were presented for 1 s, without squares.

2.2.4.2. Results

In the detection task, younger adults (*M* = 100.0%) were significantly more accurate than older adults (*M* = 95.1%) in the detection of target squares during the encoding phase, $t(46) = 3.37$, $p = 0.003$. Most importantly, RTs were considerably slower in older (*M* = 572 ms) than in younger participants (*M* = 382 ms), $t(46) = -6.50$, $p < 0.001$. Lastly, older adults exhibited more false alarms than younger adults, although the difference just approached the significance level, *M* = 1.86 vs. *M* = 0.25, $t(46) = -2.07$, $p = 0.05$.

Regarding the memory task, false alarms to new (unstudied) words were comparable between younger (*M* = 0.27) and older adults (*M* = 0.29), $t(46) = -0.52$, $p = 0.61$. Nonetheless, to be consistent with previous experiments, the main analysis was still conducted on corrected recognition scores, computed as: hits – false alarms (see Figure 2.3). A 2 (Group: younger vs. older adults) × 3 (Type of Trial: target, distractor and baseline words) mixed ANOVA showed: a) a marginal main effect of Group, $F(1, 46) = 3.77$, $p = 0.06$, $\eta_p^2 = 0.08$, indicating that corrected recognition scores tended to be higher in younger (*M* = 0.29) than in older (*M* = 0.21) adults; b) no significant main effect of Trial Type, $F(2, 92) = 2.34$, $p = 0.10$, $\eta_p^2 = 0.05$; and c) a marginal two-way interaction between Trial Type and Group, $F(2, 92) = 2.60$, $p = 0.08$, $\eta_p^2 = 0.05$. A follow-up analysis of simple effects confirmed that the ABE was robust in younger adults, $F(2, 45) = 4.81$, $p = 0.013$, $\eta_p^2 = 0.18$, with target words (*M* = 0.35) being recognized significantly better than distractor words (*M* = 0.26, *p* = 0.01), and marginally better than baseline words (*M* = 0.27, *p* = 0.06); baseline and distractor words did not differ between them (*p* = 1,00). On the other hand, no ABE was observed in older adults, $F(2, 45) = 0.036$, $p = 0.96$, $\eta_p^2 = 0.002$. In addition, the same analysis revealed that younger adults (M = 0.35) outperformed older adults (M = 0.22) in the recognition of target words, $F(1, 46) = 5.71$, $p = 0.021$, $\eta_p^2 = 0.11$, whereas the two groups did not differ in the recognition of distractor and baseline words, $F(1, 46) = 1.10$, $p = 0.30$, $\eta_p^2 = 0.023$ and $F(1, 46) = 1.41$, $p = 0.24$, $\eta_p^2 = 0.030$.

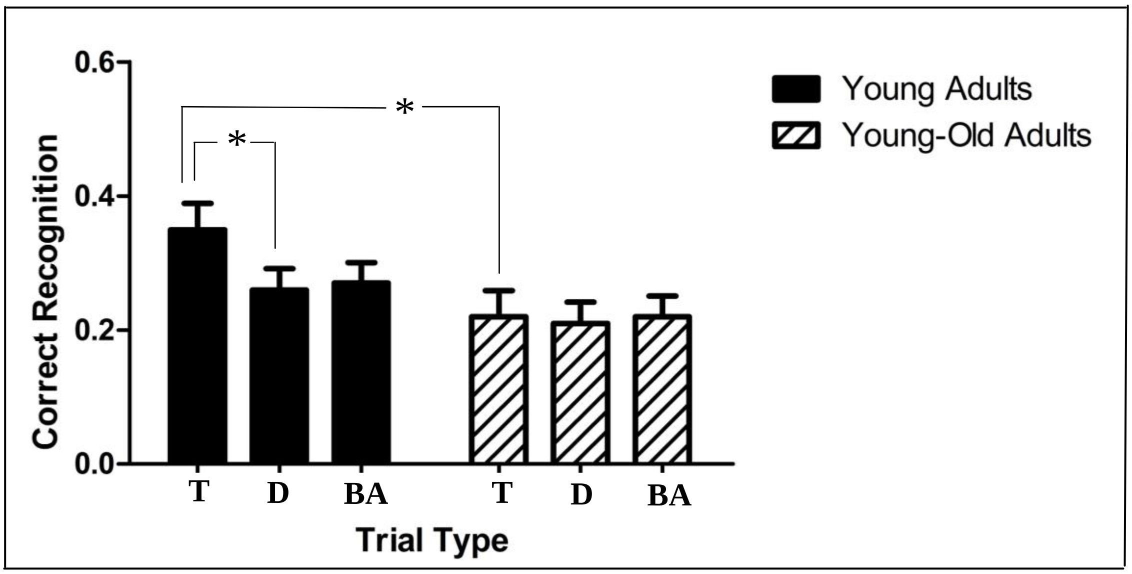

Figure 2.3. Experiment 3 (words encoded for 1000 ms, incidental instructions): Mean proportions of Corrected Recognition (hits – false alarms) in young and young-old adults, as a function of Trial Type. Bars represent standard errors. *: $p < 0.05$; ***: $p < 0.001$.

Since Experiments 2 and 3 used the same materials but different encoding times, it is interesting to ascertain whether this manipulation affected the size of the ABE. To this purpose, the corrected recognition scores of younger adults in these two experiments were combined and analyzed with a 3 (Type of Trial: target, distractor and baseline images) × 2 (Encoding Time: 500 vs. 1000 ms) mixed ANOVA. We limited this analysis to younger adults, because no ABE was obtained in older adults in both experiments. In addition to the significant main effect of Trial Type, $F(2, 82) = 16.96$, $p < 0.001$, $\eta_p^2 = 0.029$, the results revealed a marginal main effect of Encoding Time, $F(1, 41) = 3.14$, $p = 0.083$, $\eta_p^2 = 0.071$, indicating that corrected recognition scores tended to increase when participants were given more time to encode the words ($M = 0.29$ vs. $M = 0.25$). Importantly, however, the two-way interaction did not reach the significance level, $F(2, 82) = 2.09$, $p = 0.13$, $\eta_p^2 = 0.049$, suggesting that the size of the ABE was roughly equivalent in Experiments 2 and 3. This conclusion is consistent with that reached in two previous studies (Mulligan & Spataro, 2015; Spataro et al., 2017), in which the magnitude of the ABE did not vary when the words were presented for 500 and 1500 ms (though note that the attentional boost was abolished at 4000 ms).

2.2.4.3. Discussion

Experiment 3 provided the first evidence indicating that the ABE was eliminated in older adults even when they were given more time to focus their attention on the memory task. Such an assumption was bolstered by the finding that responses to the target squares were significantly slower and less accurate in older than in younger participants. Even in these conditions, however, the ABE was completely abolished in the older group, who instead exhibited a significant deficit in the recognition of words presented concurrently with target squares during the encoding phase. According to our initial hypotheses, both of these results are consistent with the idea that the detection of target squares required more attention resources in older than in younger adults, and that these resources were subtracted from the encoding of target-associated stimuli (Craik & Byrd, 1982; Kilb & Naveh-Benjamin, 2015; Rabinowitz et al., 1982). Thus, when considered together, the data reported in Experiments 1-3 suggest that the mechanisms underlying *temporal selective attention* (Olivers & Meeter, 2008; Swallow & Jiang, 2013) are impaired in healthy aging irrespective of the degree of emphasis placed on the memory task. Experiment 4 will provide additional support to this conclusion by using intentional instructions during the encoding phase.

Of note, Experiment 3 provided no evidence in support of the inhibitory hypothesis (de Fockert et al., 2009; Haring et al., 2013; Hasher et al., 1999; Healey et al., 2014): as in Experiments 1 and 2, older adults recognized distractor words as well as baseline words, and the two groups showed equivalent memory for the words encoded with distractor squares.

2.2.5. Experiment 4

Experiment 4 used the same materials (words) and procedures as in Experiments 2 and 3, with the exception that the instructions during the encoding phase were intentional. That is, both younger and older participants were explicitly told to memorize the words into memory and they were fully informed about the upcoming recognition test. Given the results of the combined analysis of Experiments 2 and 3, we decided to use a 500-ms presentation time during the study phase, since no further increase of the ABE was obtained at 1000 ms. We speculated that the use of intentional instructions should lead participants to emphasize the memory task more than in Experiments 1-3, which employed incidental instructions.

2.2.5.1. Materials & Method

2.2.5.1.1. Participants

Twenty healthy young-old adults between 60 and 75 years (14 females; mean age = 65.95 years) volunteered to participate. Twenty students of the University Sapienza of Rome, from 18 to 35 years old, served as controls (13 females; mean age = 24.25 years). Table 2.4 illustrates that education was greater for younger (*M* = 14.85) than for older adults (*M* = 11.70), $t(38) = 2.71$, $p = 0.01$. As concerns the WAIS subtests (Wechsler, 2013; Orsini & Pezzuti, 2013), significant differences between the two groups (favoring younger adults) were obtained only in the two processing speed measures: $t(38) = 4.06$, $p < 0.001$ for Symbol Search and $t(38) = 4.91$, $p < 0.001$ for Digit Symbol-Coding, respectively. Like in Experiment 4, older adults scored within the range of normality in the Mini Mental State Examination (Folstein et al., 1975; Magni et al., 1996).

Measures	**Experiment 4**		
	Younger	Older	t-test
Age (years)	24.25 (3.46)	65.95 (3.47)	-38.04 ***
Education (years)	14.25 (3.19)	11.70 (3.77)	2.31 *
Digit Span (forward)	9.40 (2.09)	9.65 (2.43)	-0.35
Digit Span (backward)	8.35 (2.74)	8.30 (2.60)	0.06
Symbol Search	34.05 (9.29)	22.65 (8.46)	4.06 ***
Digit Symbol-Coding	70.5 (10.5)	51.3 (13.9)	4.01 ***
Vocabulary	37.80 (9.12)	32.75 (9.37)	1.73
MMSE	NA	28.14 (1.39)	NA

Table 2.4. Mean scores and *t*-tests for the demographic and cognitive measures of younger and older adults in Experiments 4. Standard deviations are reported in parenthesis. For the WAIS-IV subtests, raw scores are reported. *: $p < 0.05$; ***: $p < 0.001$.

2.2.5.1.2. *Materials*

The same set of words selected for Experiment 2 were also employed in Experiment 4.

2.2.5.1.3. *Procedure*

The procedure was the same as that illustrated in Experiment 2 (encoding time was set at 500 ms), with the exception that the instructions during the encoding phase were intentional. That is, participants were told to read aloud the words and memorize them in view of an upcoming recognition test, while simultaneously pressing the spacebar whenever they detected a target square.

2.2.5.2. Results

In the detection task, younger adults (*M* = 96%) were consistently and significantly more accurate than older adults (*M* = 87%) in the detection of target squares during the encoding phase, $t(38) = 2.37$, $p = 0.02$; furthermore, older adults showed a trend towards making more false alarms to non-target squares: *M*(older adults) = 1.25 vs. *M*(younger adults) = 0.55, $t(38) = -1.72$, $p = 0.09$. However, like in Experiments 1 and 2, the mean RTs were comparable across the two groups, being *M* = 307 ms for younger adults and *M* = 308 ms for older adults, $t(38) = -0.08$, $p = 0.93$.

In the recognition test, the proportions of false alarms were significantly greater in the older (*M* = 0.44) than in the younger group (*M* = 0.28), $t(38) = -3.74$, $p = 0.001$. Therefore, the primary analysis was again conducted on corrected recognition scores (hits −false alarms) (see Figure 2.4). A 2 (Group: younger vs. older adults) × 3 (Type of Trial: target, distractor and baseline words) mixed ANOVA showed: a) a significant main effect of Group, $F(1, 38) = 5.04$, $p = 0.03$, $\eta_p^2 = 0.12$, with younger adults performing better than older adults (*M* = 0.26 vs. *M* = 0.19); b) a significant main effect of Trial Type, $F(2, 76) = 4.26$, $p = 0.02$, $\eta_p^2 = 0.10$; and c) a significant two-way interaction between Group and Trial Type, $F(2, 76) = 6.02$, $p = 0.004$, $\eta_p^2 = 0.14$. A follow-up analysis of simple effects confirmed that the effect of Trial Type was significant in younger adults, $F(2, 37) = 8.29$, $p = 0.001$, $\eta_p^2 = 0.31$. For this group, the recognition of target words (*M* = 0.36) was more accurate than the recognition of distractor (*M* = 0.17, $p = 0.001$) and baseline words (*M* = 0.24, $p = 0.01$), which did not differ between them ($p = 0.33$). In contrast, the effect of Trial Type was absent in older adults, $F(2, 37) = 0.21$, $p = 0.81$, $\eta_p^2 = 0.012$, with no significant difference between the three conditions. Replicating Experiment 1 and 3, this same analysis indicated that older adults were less efficient than younger adults in the recognition of target words, *M*(younger adults) = 0.36 vs. *M*(older adults) = 0.19, $F(1, 38) = 16.03$, $p < 0.001$, $\eta_p^2 = 0.230$. In contrast, the two groups did not differ in the recognition of distractor and baseline words, $F(1, 38) = 0.45$, $p = 0.51$, $\eta_p^2 = 0.012$ and $F(1, 38) = 2.01$, $p = 0.16$, $\eta_p^2 = 0.05$, respectively.

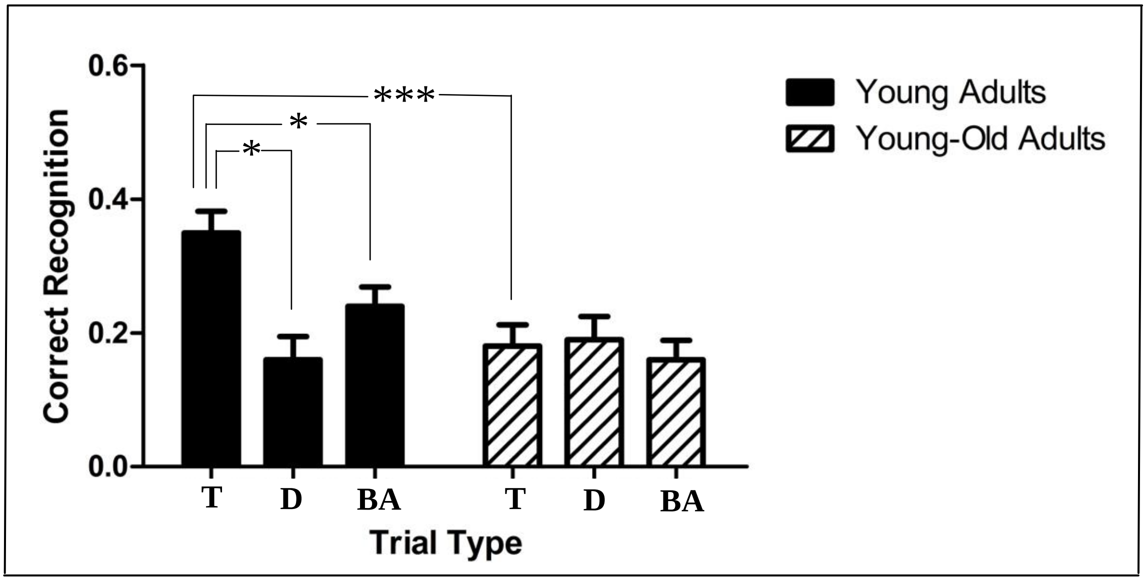

Figure 2.4. Experiment 4 (words encoded for 500 ms, intentional instructions): Mean proportions of Corrected Recognition (hits – false alarms) in young and young-old adults, as a function of Trial Type. Bars represent standard errors. *: $p < 0.05$; ***: $p < 0.001$.

Since Experiments 2 and 4 used the same materials and encoding times (500 ms) but different instructions, it is important to ascertain whether the use of intentional instructions increased the size of the ABE (see Swallow & Jiang, 2013). To this purpose, the corrected recognition scores of younger adults in these two experiments were combined together and analyzed with a 3 (Type of Trial: target, distractor and baseline images) × 2 (Instructions: implicit vs. explicit) mixed ANOVA. The analysis revealed a main effect of Trial Type, $F(2, 74) = 19.01$, $p < 0.001$, $\eta_p^2 = 0.34$, with target words ($M = 0.35$) being recognized better than distractor and baseline words ($M = 0.16$ and $M = 0.23$, all *p*s < 0.003); however, neither the main effect of Instructions nor the interaction between Instructions and Trial Type reached the significance level, $F(1, 37) = 0.00$, $p = 0.98$, $\eta_p^2 = 0.00$ and $F(2, 74) = 0.01$, $p = 0.99$, $\eta_p^2 = 0.00$, respectively. Thus, it appears that the size of the ABE was unaffected by the use of intentional instructions.

2.2.5.3. Discussion

Experiment 4 provided additional evidence indicating that the ABE was absent in healthy older adults even when the instructions were intentional and therefore emphasized the memory task. In agreement with this assumption, the use of explicit instructions led to a substantial decrease in the accuracy of target detection in older participants. As in the previous experiments, the older group exhibited a significant deficit in the recognition of target-associated words, further confirming the idea that the increased attention resources required by the detection task impaired the encoding of the background stimuli (Craik & Byrd, 1982; Kilb & Naveh-Benjamin, 2015; Rabinowitz, Craik & Ackerman, 1982); in contrast, no difference was observed in the recognition of distractor-associated words, again disconfirming the predictions of the inhibitory hypothesis (de Fockert et al., 2009; Haring et al., 2013; Hasher et al., 1999; Healey et al., 2014).

2.2.6. Combined analysis of Experiments 2-4

In all experiments, older adults reported to have a lower number of years of education, compared to younger adults (see Table 2.1 & 2.2 & 2.3 & 2.4), although the difference reached the significant level only in Experiments 1 and 4. As noted above, we did not correct statistical analyses for this factor, because, as illustrated by Miller & Chapman (2001), this procedure would violate the assumptions of the analysis of covariance. However, to address this problem, we combined the corrected recognition scores of Experiments 2-4 (i.e., the experiments using verbal materials) and then divided the sample of younger adults in two halves, based on the median of their education. The rationale was to compare the performance of older adults with that of younger adults with similar (low) levels of education: if the ABE is significant in the latter, but not in the former group, then it can be safely concluded that the educational confound did not impact our main conclusions about the absence of the ABE in older participants.

Overall, the combined analysis was performed on 126 participants: 63 older adults and 63 younger adults, which differed significantly in terms of education, *M*(older adults) = 12.70 years vs. *M*(younger adults) = 14.41 years, $t(124) = 2.40$, $p = 0.018$. The group of younger adults was therefore divided in two subgroups having either high ($M = 17.28$ years) or low education ($M = 11.97$ years). Importantly, preliminary *t*-test analyses confirmed that there was no difference between older adults and younger adults with low education, $t(95) = 0.86$, $p = 0.36$. A 3 (Group: younger adults with high education, younger adults with low education, and older adults) × 3 (Type of Trial: target, distractor and baseline words) mixed ANOVA showed significant main effects of both Group, $F(2, 123) = 3.15$, $p = 0.046$, $\eta_p^2 = 0.049$, and Trial Type, $F(2, 246) = 22.04$, $p < 0.001$, $\eta_p^2 = 0.15$, which were however qualified by a significant two-way interaction, $F(4, 246) = 5.20$, $p < 0.001$, $\eta_p^2 = 0.078$. A follow-up analysis of simple effects confirmed that the effect of Trial Type was significant in the two groups of younger adults, $F(2, 122) = 13.73$, $p < 0.001$, $\eta_p^2 = 0.18$ for the group with high education and $F(2, 122) = 8.43$, $p < 0.001$, $\eta_p^2 = 0.12$ for the group with low education; on the other hand, no effect was found in of older adults, $F(2, 122) = 0.85$, $p = 0.43$, $\eta_p^2 = 0.014$. More specifically, in the two groups of younger adults the recognition of target words was significantly higher than the recognition of both distractor and baseline words (all *p*s < 0.004), confirming that a robust ABE was observed. In contrast, the analysis on the older group revealed no significant difference between the three conditions (all *p*s > 0.59). To summarize, these findings suggest that the absence of the ABE in the group of older adults was not merely due their lower educational level.

2.2.7. General Discussion

In four experiments, we compared the Attentional Boost Effect (ABE) in younger and older adults, using a modified paradigm illustrated by Swallow and Jiang (2014) and varying several factors: the nature of the background stimuli (images in Experiment 1 vs. words in Experiment 2-4), the length of the encoding trials (500 ms in Experiments 1, 2 and 4 vs. 1000 ms in Experiment 3) and the type of study-phase instructions given to participants (incidental in Experiments 1-3 vs. intentional in Experiment 4). In all cases, the results clearly indicated that the memory facilitation produced by target detection was abolished in the group of older adults, whereas it was always robust and significant in the group of younger adults (the latter result replicating the standard pattern reported in literature: Mulligan et al., 2014; Mulligan & Spataro, 2015; Spataro et al., 2013, 2015, 2017; Rossi-Arnaud et al., 2017; Swallow & Jiang, 2010, 2014). More importantly, in Experiments 1, 3 and 4, older adults performed significantly worse than younger adults in the recognition of target stimuli, whereas the two groups were equally accurate in the recognition of distractor and baseline stimuli: thus, the main effect of Group was almost entirely driven by age-related differences in the elaboration of the stimuli associated to target squares. This pattern of results is consistent with the proposal that the detection task required more attention resources in older than in younger adults. As illustrated above, because the ABE represents a tradeoff between attentional competition and attentional facilitation (Swallow & Jiang, 2010, 2013), and ageing is associated to a reduction of the overall amount of cognitive resources (the *reduced attentional resources hypothesis*: Craik & Byrd, 1982; Kilb & Naveh-Benjamin, 2015; Rabinowitz et al., 1982), any increase in the attentional requirements of the detection task should result in an impairment in the encoding of target-associated stimuli, and thus a reduction, or even a complete elimination, of the memory facilitation produced by the ABE. In agreement, Swallow & Jiang (2010, Exp.5) showed that enhancing the difficulty of the detection task by requesting different responses to different target items was sufficient to cancel the ABE in younger adults. The data obtained in our experiments might therefore suggest that healthy aging is associated with a naturally-occurring increase in the attentional demands of target detection which is sufficient to eliminate the memory facilitation typically observed in the ABE paradigm. In Experiments 3 and 4, when the longer encoding time or the explicit instructions led older adults to give more emphasis to the encoding of the background stimuli, they showed longer RTs and/or lower accuracy rates in the detection of target squares, suggesting an increased difficulty of the secondary task. On the other hand, when the instructions were incidental (in Experiments 1 and 2), older adults appeared to emphasize the detection task more than the encoding task, as indicated by the fact that their performance (in terms of RTs and accuracy) resembled that of the younger group. Even in these cases, however, the recognition of target-associated stimuli was significantly worse in older than in young participants, suggesting that the maintenance of a fast and accurate performance in the detection task required more attention resources in the older group even in the absence of behavioral deficits (which is in line with the results illustrated by Daffner et al., 2005, 2006, and by Mott et al., 2014).

In the modified ABE paradigm (Swallow & Jiang, 2014), the difference between the recognition of baseline and distractor stimuli was taken to reflect the influence of inhibitory processes due to distractor rejection. The authors contended that distractor inhibition played no role in the ABE, since the recognition of distractor and baseline images was equally accurate (and significantly lower than the recognition of target images). Our data with younger adults confirmed this conclusion across all experiments. What is more interesting, however, is that there was no evidence that the inhibition of distractors was less efficient in older than in younger adults: if this had been the case, an advantage in the recognition of distractor over baseline stimuli should have been found in the older group. Such a result is apparently in contrast with behavioral and neurophysiological evidence suggesting that aging reduces the ability to inhibit distractor processing (de Fockert, Ramchurn, Van Velzen, Bergström, & Bunce, 2009; Haring et al., 2013; Hasher, Zacks, & May, 1999; Healey, Ngo, & Hasher, 2014). In particular, in several studies delineating the so-called "hyper-binding" effect, older participants have been found to remember distractor words significantly better than younger adults in both explicit and implicit tasks (Campbell, Hasher, & Thomas, 2010; Rowe, Valderrama, Hasher, & Lenartowicz, 2006). Of course, there are several methodological differences between the two paradigms that prevent a direct comparison. Among them, a critical point is that participants in a typical ABE experiment are explicitly told to give attention to the background stimuli, whereas in the hyper-binding experiments the instructions are to ignore the distractor words. Such a difference might potentially explain the discrepant outcomes, since there is ERP evidence indicating that older adults exhibit increased processing of distracting stimuli when they are unattended (as in the hyper-binding experiments), but not when they are attended (de Fockert et al., 2009).

In the dual-task interaction model, the beneficial influence of target detection on explicit memory are driven by transient increases in the release of norepinephrine from the locus coeruleus (Swallow & Jiang, 2013). Although not directly investigated, the results found in our experiments could be consistent with this proposal. More specifically, the hypothesized role of norepinephrine in the ABE fits well with the effects of aging on other memory abilities for which the involvement of the noradrenergic system is well established. In particular, pattern separation refers to a process by which similar stimuli can be stored as distinct memories (Yassa & Stark, 2011). In a noteworthy experiment, Segal, Stark, Kattan, Stark and Yassa (2012) reported that showing participants fearful images in a pre-training task increased the levels of salivary alpha-amylase, which is a biomarker for norepinephrine; furthermore, the size of the increase correlated with pattern separation performance in a later recognition test. Interestingly for the present purposes, pattern separation scores show a significant, negative correlation with age, such that this ability is strongly reduced in 60- to 74-year-old adults (Stark, Yassa, Lacy, & Stark, 2013).

A recent study by Spataro et al. (2017) has shown that the ABE enhanced category-cued recall (an explicit task based on item-specific encoding), but had no significant impact on category exemplar generation (an implicit task based on relational encoding), and concluded that target detection operated primarily by enhancing the processing of item-specific information (Hunt & McDaniel, 1993). When viewed in this perspective, the finding of a reduced ABE in older adults aligns with the evidence obtained in studies examining other memory phenomena driven by increased item distinctiveness (see Hunt & Worthen, 2006, for an extensive review) – including the bizarreness effect (i.e., the memory benefit for unusual versus common items: McDaniel & Einstein, 1986) and the production effect (i.e., the memory benefit for items read aloud relative to words read silently during study: MacLeod, Gopie, Hourihan, Neary, & Ozubko, 2010). Like the ABE, both of these effects are substantially reduced by healthy ageing (see Gounden & Nicolas, 2012, Experiment 1, for the bizarreness effect and Lin & MacLeod, 2012, for the production effect). Thus, the current results concur with other data in suggesting that older adults can be less efficient in using item-specific encoding processes to assist remembering (Smith, Lozito, & Bayen, 2005), although there might be exceptions. In facts, Geraci, McDaniel, Manzano, and Roediger (2009) and Smith (2011) reported intact isolation effects in older participants, and Gounden and Nicolas (2012, Experiment 2) found that aging did not diminish the orthographic distinctiveness effect. To account for these contradictory findings, Gounden and Nicolas (2012) proposed that the orthographic distinctiveness effect was mediated by more automatic processing, which, by definition, was less influenced by the negative consequences of healthy aging.

As a last point, we would like to discuss a potential limitation and suggest a couple of extensions. As concerns the limitation, the concept of the Useful Field of View (UFOV) refers to the visual field area over which information can be acquired in a brief glance without eye or head movements (Ball & Owsley, 1993). More specifically, the DA condition of the UFOV test discussed by Edwards et al. (2006) involved the identification of a central target (the silhouette of a truck or car) presented in a 3 cm × 3 cm fixation box and the simultaneous localization of a peripheral target (the silhouette of a car) which was placed at a fixed eccentricity of 12.5 cm from the center target and was presented at one of eight radial positions. In these conditions, Edwards et al. (2006) estimated that the mean display duration at which older adults (*N* = 2759, between 65 and 94 years of age) performed accurately on 75% of the trials was 131.59 ms (range: 16-500 ms). Since the UFOV performance shows a strong positive relation with age (Sekuler, Bennett & Mamelak, 2000), the possibility arises that the ABE was absent in our experiments because the participants did not have sufficient resolution to process the picture/word and target/distractor stimuli in parallel. Although we cannot definitively rule out this explanation, we believe that the age-related reduction in the UFOV cannot explain the elimination of the ABE, especially when using verbal materials (Experiments 2-4). This is because the to-be-remembered words were placed only 1 cm above the target/distractor squares – a distance considerably lower than that employed by Edwards et al. (2006). In practice, this means that, in Experiments 2-4, the squares and the target words were almost always presented in a 3 cm × 3 cm fixation box similar to that employed by Edwards et al. (2006). These authors estimated that the mean display duration needed by older adults to identify a target in this box was 30.66 ms. Thus, it appears that 500 ms, and moreover 1000 ms in Experiment 3, were sufficient to allow older adults to process the words and the squares in parallel. This is further attested by the fact that we always required participants to read aloud the words in Experiments 2-4, to ensure correct identification. The fact that none of our older adult participants had any difficulty in reading the words, coupled with the fast RTs in the detection task (particularly in Experiments 2 and 4), makes a UFOV explanation of our results very unlikely.

Turning to consider possible extensions, future studies might want to extend our findings at least in two directions. First, we employed an explicit recognition test, but the ABE has been also obtained with implicit memory tasks (lexical decision and word-fragment completion: Spataro et al., 2013). In the present context, the use of implicit tests might be relevant because DA at encoding has been shown to have minimal effects on repetition priming in both lexical decision (Mulligan & Peterson, 2008) and word-fragment completion (Mulligan & Hartman, 1996). The implication is that priming should be largely insensitive to the increase in the costs of target detection which is often associated to healthy aging (Daffner et al., 2005, 2006). The current analysis predicts that, in these modified conditions, older adults should exhibit a significant ABE and the size of their ABE should be comparable to that observed in younger adults. Second, we investigated whether aging modulated the facilitating effects of the ABE on long-term memory tasks (i.e., tasks in which the test phase occur several minutes after the encoding phase), but the extent to which a similar pattern generalizes to short-term memory tasks is currently unknown. The ABE has been adapted to examine short-term memory (Lin, Pype, Murray, & Boynton, 2010; Makovski, Swallow, & Jiang, 2011), and there is at least preliminary evidence indicating that healthy young-old adults (mean age of 63 years) retain their ability to enhance the immediate recognition of scenes presented together with targets (Szamosi, Levy-Gigi, Kelemen, & Kéri, 2013). This result points to an intriguing distinction between the short- and long-term effects of aging on the ABE.

To summarize, across four experiments using both visual and verbal materials, we found that the ABE facilitated recognition memory in younger adults, but not in older adults. According to our interpretation, the latter finding reflects an age-related enhancement in the amount of attentional resources required by the detection task, which offset the attentional facilitation enjoyed by target stimuli. Collectively, the present data reinforce the view that the ABE is based on a dynamic trade-off between attentional competition and attentional facilitation (Swallow & Jiang, 2010, 2013).

2.3. The Attentional Boost Effect in Bipolar Patients

2.3.1. Introduction

The Attentional Boost Effect (ABE) is a counterintuitive phenomenon in which the division of attention during the encoding of visual or verbal stimuli enhances later memory performance in the test phase (Swallow & Jiang, 2010; Spataro, Mulligan & Rossi-Arnaud, 2014; see Swallow & Jiang, 2013, for a review).

Several studies have examined the ABE in different clinical population (Kéri, Nagy, Levy-Gigi, & Kelemen, 2013; Levy-Gigi & Kéri, 2012; Szamosi, Levy-Gigi, Kelemen, & Kéri, 2013; Rossi-Arnaud et al., 2014). Studies using a short-term version of the ABE paradigm showed that patients with both amnestic mild cognitive impairment and post-traumatic stress disorder are severely impaired in the recognition of scenes presented together with targets compared to healthy subjects. On the contrary, they perform like controls, or have enhanced performance, in the recognition of images presented with distractors (Levy-Gigi & Kéri, 2012; Szamosi et al, 2013). Different pattern of results was obtained in patients with Parkinson disease. At the baseline, drug-naive patients had the same performance as controls. However, at follow-up, after the administration of dopaminergic medications, patients outperformed controls in both the target and distractor conditions (Kèri et al., 2013). Only one study investigated the ABE in patients using the long-term paradigm of the ABE (Rossi-Arnaud et al., 2014). The authors presented a series of pictures (Exp. 1) or words (Exp. 2) to schizophrenic patients and matched controls. Participants were instructed to memorize the pictures (or the words) and at the same time detect a red circle (target) presented at the centre of the screen. Results in the healthy control group showed the typical ABE: images or words encoded with targets were better recognized than images or words encoded with distractors. On the contrary, schizophrenic patients reported no memory advantage for the stimuli presented together with targets in the divided attention condition.

The bipolar disorder is characterized by mood alterations that includes manic or hypomanic (elevation of tone mood), depressive (decline of tone mood), and mixed episodes, intermixed with intervals of euthymic remission (DSM-5, 2014). Depressive episodes are characterized by lack of interest, loss of appetite, insomnia, fatigability and suicidal thoughts, with a very high rate of completed suicides. Manic episodes are characterized by elevated and often irritable mood, prevalent psychotic features, and increased energy, flight of ideas and rapid speech, over-activity and behavioural disinhibition that, together, contribute to high rates of recurring hospitalization

(Lim et al., 2013). Neuropsychological studies in bipolar disorder indicated cognitive disturbances during mood episodes, including impairments in executive functions (particularly abstract concept formation, set shifting and planning), sustained attention and inhibitory control, verbal memory and processing speed; evidence for an impairment in visual memory is more variable and appears to depend on the specific tests used (Quraishi & Frangou, 2002; Lim et al., 2013). There is growing evidence that individuals with bipolar disorder (BD) also show cognitive impairments when they are euthymic (in a remission phase). Several meta-analyses reported significant impairments in the cognitive domains of executive functioning, verbal memory and sustained attention (Robinson et al., 2006; Cullen et al., 2016; Palazzo et al., 2017). The presence of cognitive impairments during euthymic periods was found to be negatively associated to patients' functional outcomes (Burdick et al., 2010), and did not depend on the administration of mood regulation drugs (Goswami et al., 2002). Moreover, cognitive deficits were present in the unaffected first-degree relatives of bipolar patients who share genetic vulnerability to the disorder. Bora et al. (2009), in their meta-analysis, found that deficits in response inhibition, set shifting, executive function, verbal memory and sustained attention were common features of both patients and their relatives. For these reason, several researchers proposed that the cognitive impairments exhibited during the euthymic phase should be considered as trait markers of the disorder (Arts et al., 2008; Bora et al., 2009).

Available evidence indicates that the sustained attention abilities of bipolar patients are impaired during the manic (Clark et al 2001; Sax et al 1999) and depressive periods (Hart et al 1998; Rund et al 1992). More important for our purposes, sustained attention deficits persist during the euthymic phase of the bipolar disorder (Clark et al 2002; Harmer et al 2002; Liu et al 2002; Wilder-Willis et al 2001). A significant deficit was still observed after controlling for mild residual symptomatology (Clark et al 2002) and pharmacology treatment (Thompson et al., 2005; Goswami et al., 2009). Usually, sustained attention has been measured with continuous performance tasks (CPTs). There are different versions of this task, but in general, participants have to monitor a continuous stream of stimuli (i.e., letters or digits) to detect infrequent targets. An optimal performance in this task requires an adequate level of arousal (Parasuraman et al 1998); furthermore, executive control abilities are needed to resist distraction and inhibit responses to stimuli resembling targets (Braver et al. 2002; Manly and Robertson 1997). Several studies reported decreased target sensitivity (omission errors) in CPT tasks in euthymic patients with bipolar disorder (Bora et al., 2005; Clark et al., 2002; Clark and Goodwin, 2004; Liu et al., 2002; Swann et al., 2003), indicating an impairment in target detection. Clark et al. (2005) measured sustained attention ability in a group of euthymic bipolar patients with a rapid visual information processing (RVIP) task. Subjects were required to monitor a continuous stream of digits to detect a pre-specified digit sequence (e.g., 3-5-7, in consecutive order). Results showed significant sustained attention deficits in euthymic patients. Compared to control subjects, these patients exhibited reduced target sensitivity and slowed response latencies. However, contrary to what usually reported with patients in acute manic episodes (Clark et al 2001; Swann et al 2003), euthymic patients did not show a tendency to commit more false alarms than healthy subjects. As reported in other studies, the sustained attention deficit did not correlate with sub-clinical ratings of depressive and manic symptoms that commonly persist during periods of remission and can account for cognitive impairment in other domains (Ferrier et al 1999; Clark et al 2002). Sepede et al. (2012) investigated sustained attention in euthymic bipolar patients and first-degree relatives, using a continuous performance task (CPT). They presented a series of digits visually, one per time, and participants had to detect a specific digit (i.e., number "8"). Results indicated a low level of target accuracy in both euthymic patients and their relatives, compared to controls. However, the two groups did not commit more false alarms than healthy subjects (replicating Clark et al., 2005). The authors suggested that the impairment in target detection might be considered as a possible trait marker for bipolar patients. However, it is important to highlight that other studies did not replicate these findings (Bozikas et al., 2005; Robertson et al., 2003).

Another important difficulty usually reported in bipolar patients, even in a euthymic state, is a deficit in inhibition ability. Frangou et al. (2005) suggested that the lack of inhibitory control represented the core deficit in a sample of euthymic bipolar patients. Mur et al. (2007) found that euthymic patients performed worse than healthy subjects in executive, inhibitory and processing speed tasks; however, checking for the pharmacology therapy, only the inhibition impairment remained significant. Moreover, several studies indicated that inhibitory processes are mediated by regions that are also implicated in the pathophysiology of bipolar disorder (Blumberg et al., 2003; Aron et al., 2003; Rubia et al., 2003), even during euthymia phase (Townsend et al., 2012). There are also studies in which euthymic patients and healthy controls performed inhibitory tasks with the same accuracy. Nonetheless, the EEG revealed different patterns of brain activation in the two groups (Swann et al., 2013; Morsel et al., 2017), suggesting the use of a compensatory mechanism in euthymic bipolar patients (see Haldane et al., 2008, for a neuroimaging studies reporting analogues results). For example, Morsel et al., (2017) measured the performance in a Go/NoGo task in euthymic bipolar patients, while electroencephalogram was recorded. Patients showed the same behavioural performance as controls. However, they had a different pattern of brain activation: patients showed reduced NoGo N2 amplitudes, reflecting difficulties in the early stages of the inhibition process, and increased NoGo P3 amplitudes, reflecting an overactive cortical system.

Because the two groups did not differ in their performance, the authors concluded that patients compensated their difficulties in the early stages of inhibition by increasing cortical activation.

The aim of the present study was to investigate the presence of the Attentional Boost Effect (ABE) in a sample of euthymic bipolar patients using the long-term paradigm. To do this, we used the latest version of the ABE paradigm. Swallow & Jiang (2013) presented a long sequence of faces flanked by two target squares (e.g., orange), two distractor squares (e.g., blue) or no squares – the latter condition representing the baseline. The instructions were to study the faces and simultaneously press the spacebar when the target squares appeared on the screen (no action was required in response to the distractor squares). When memory for the faces was later probed in a recognition task, the results showed that the performance was significantly better for the faces encoded in the target condition than for the faces encoded in the distractor or no-square conditions, which did not differ between them.

Given the previously discussed literature showing the presence of cognitive disorders also in the euthymic phase, we hypothesized that bipolar patients would not exhibit a significant advantage for stimuli encoded with targets. The reason was that cognitive abilities such as sustained attention, executive function and inhibitory control showed an impairment also in the remission phase of the bipolar disorder (Robinson et al., 2006; Cullen et al., 2016; Palazzo et al., 2017). More in particular, the predominance of one of the two cognitive deficits (attention or inhibitory impairment) should led to the same general prediction (that the ABE should be eliminated in the patient group), but for different reasons. If patients are more compromised in their attentional abilities, we expected that the detection task was rather difficult in terms of cognitive resources required. According to Swallow & Jiang (2010, 2013) ABE represents a dynamic trade-off between *attentional competition* (items in the divided attention (DA)-distractor condition were recognized worse than full attention (FA) performance – the typical negative interfering effect of DA on memory encoding) and *attentional boost* (items in the DA-target condition were boosted to the level of FA performance). When the additional attentional requests needed to detect the target are relatively low (as in the simple detection task), the two effects produce a clear facilitation. As attentive requests for performing the secondary task increase, interference goes beyond facilitation, eliminating the effect. In support of this claim, Swallow and Jiang (2010, Exp.5) reported that a modest increase in attentional competition during the target detection task was sufficient to eliminate the ABE. We thus expected that the detection task should be more difficult (in terms of cognitive resources) in patients than in healthy controls. On the other hand, if the inhibitory deficit was predominantly, we expected that the advantage of target-associated stimuli should be eliminated because of a selective increase in the recognition of distractor-associated stimuli. If this were the case, we should expect distractor-associated stimuli to be recognized significantly better than baseline stimuli. However, in both cases, the net consequence should be a reduction or the elimination of the facilitation effect due to the detection of the target.

2.3.2. Materials & Method

2.3.2.1. Participants

Twenty-eight euthymic bipolar patients (BP) Type I, between 18 and 59 years (15 females; age M = 43.93 years, SD = 13.37; education M = 13.61, SD = 3.26) were recruited for the current study from the Psychiatric ward of the Sant'Andrea Hospital in Rome. The diagnosis of bipolar disorder was made according of the inclusion criteria of the DSM-5 (2014). To be included, patients had to be in a euthymic phase (APA, DSM-5). Thirty healthy subjects (HS), from 18 to 59 years old (20 females; age M = 38.60, *SD* = 12.93; education M = 14.47, SD = 3.29), were recruited as controls. Four participants (one from the BP group and three from the HS group) were excluded because their accuracy at the memory test was under the two standard deviations from the mean. The two groups were equated for age, $t(52) = -1.44$, $p = 0.15$, education, $t(52) = 1.41$, $p = 0.16$, and gender, χ (1) = 1.23, p = 0.27. The demographic characteristics of the final two groups were reported in Table 2.5. Approval from the Ethical Committee of Sant'Andrea Hospital and written informed consent were obtained before study initiation. Subjects participated voluntarily in the study.

Four subtests of the WAIS-IV (Wechsler, 2013; Orsini & Pezzuti, 2013) were administered to all participants – Digit span (forward and backward) to evaluate working memory, and Symbol Search and Digit Symbol-Coding to evaluate processing speed (see Table 2.5). Healthy subjects performed better than bipolar patients in all subtests: $t(52) = 2.40$, $p = 0.02$, for the Digit span forward; $t(52) = 2.32$, $p = 0.02$, for the Digit span backward; $t(52) = 2.63$, $p = 0.01$ for the Symbol Search; $t(52) = 2.23$, $p = 0.03$, for the Digit Symbol-Coding.

	BP (N = 27)	**HS (N =27)**	**statistics**
Age (years)	43.5 (13.4)	38.2 (13.5)	t = -1.44
Education (years)	13.5 (3.2)	14.7 (3.3)	t = 1.41
Gender (M/F)	14/13	18/9	χ = 1.23
Digit Span (forward)	9.3 (1.7)	10.6 (2.2)	t = 2.4 *
Digit Span (backward)	7.4 (2.4)	9.04 (2.7)	t = 2.3 *
Symbol Search	27.9 (6.7)	33.5(8.6)	t = 2.6 **
Digit Symbol-Coding	59.9 (15.7)	69.9 (17.2)	t = 2.2 *

Table 2.5. Mean scores, *t*-tests and *chi*-square for the demographic and cognitive measures of euthymic bipolar patients and healthy subjects. Standard deviations are reported in parenthesis. For the WAIS-IV subtests, raw scores are reported. *: $p < 0.05$; **: $p < 0.01$.

Based on previous studies about the Attention Boost Effect (ABE) in aging (see chapter 2.2), using the last paradigm (Swallow & Jiang, 2014), the effect can be observing in a young-adult group (range 18-35), but it is absent in young-old people (range 60-75). The ABE has never been studied first in a group of adults (between 35 and 60 years) using this paradigm. Only a previous study by Rossi-Arnaud et al. (2014), using the first long term paradigm of the ABE, compared schizophrenic patients and healthy subject in a range of age matched to ours. To be sure that the ABE was not influenced by the age range of our participants, we conducted analysis also dividing patients and control group on the basis of age in young-adults (range 18-35 years) and adults (range 36-59 years). In each age range, the two groups were equated for age, gender and cognitive scores; only in the adults age range, the two groups were equated also for education (see Table 2.6).

Age range	**18-35 (N = 23)**			**36-60 (N = 31)**		
	BP (N = 10)	*HS (N =13)*	*statistics*	*BP (N = 17)*	*HS (N =14)*	*statistics*
Age (years)	27.7 (5.1)	25.2 (3.5)	*t* = -1.37	52.8 (5.5)	50.2 (5.5)	*t* = -1.28
Education (years)	13.6 (1.2)	16.0 (2.7)	*t* = 2.63 *	13.4 (3.6)	13.6 (4.2)	*t* = 0.11
Gender (M/F)	5/5	4/9	χ = 0.88	8/9	5/9	χ = 0.41
Digit Span (forward)	9.9 (1.6)	11.1 (2.4)	*t* = 1.35	9.0 (1.8)	10.2 (2.0)	*t* = 1.7
Digit Span (backward)	8.3 (2.4)	10.3 (2.4)	*t* = 1.99	6.9 (2.4)	7.9 (2.4)	*t* = 1.1
Symbol Search	31.4 (6.5)	36.8 (9.2)	*t* = 1.56	25.9 (6.1)	30.4 (6.9)	*t* = 1.9
Digit Symbol-Coding	71.10 (16.2)	80.8 (14.5)	*t* = 1.51	53.3 (11.3)	59.8 (12.8)	*t* = 1.5

Table 2.6. Mean scores, *t*-tests and *chi*-square for the demographic and cognitive measures of euthymic bipolar patients and healthy subjects divided on the basis of age range. Standard deviations are reported in parenthesis. For the WAIS-IV subtests, raw scores are reported.

In the present experiment, we chose not to correct statistical analyses for education, because the resulting ANCOVA would violate the assumption that the experimental groups should not differ on the covariate (see Miller & Chapman, 2001, for a discussion about the misuses of ANCOVA).

2.3.2.2. Materials

A critical set of 45 neutral pictures were selected from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008) – valence: *M* = 5.28, on a 9-point Likert scale ranging from *1 = unhappy* to *9 = very happy*; arousal: *M* = 3.18, on a 9-point Likert scale ranging from *1 = relaxed* to *9 = excited*. This initial set was further divided in three subgroups of 15 images. Each image could be associated to a red square (target condition), a green square (distractor condition) or presented on its own, without squares (baseline condition). The use of the three subsets of images in the different encoding conditions was counterbalanced across participants. An additional set of 124 non-critical neutral images were also selected from the IAPS, to be used as practice (5 images) and filler items (74 images) during the encoding phase, or as foils in the recognition task (45 images). Foils were as similar as possible to the critical images in terms of valence (*M* = 5.29) and arousal (*M* = 3.17). All images were pre-processed with Adobe Illustrator CS6 and presented on the 15" monitor of an HP Pavilion notebook using the software SuperLab 4.0 (Cedrus Corporation, San Pedro, CA). Viewing distance was about 50 cm.

2.3.2.3. *Procedure*

The procedure was the same as that illustrated in Experiment 1 in older adults (paragraph 2.2.2.1.3). The experiment comprised an encoding phase, a 15-min interval and a test phase. In the encoding phase, participants were presented with a total of 124 images, at a rate of 500 ms/picture (no inter-stimulus interval). For target and distractor trials, one image (1024 × 628 pixels) and one square (70 × 70 pixels; red or green, placed at the centre of the image) appeared simultaneously on the screen for 100 ms, after which only the image remained visible for an additional 400 ms. For baseline trials, the images were presented for 500 ms, without squares. The entire presentation was divided in 16 continuous blocks of 5 images each (1 practice block plus 15 critical blocks). Each block included 1 target image (presented with a red square), 1 distractor image (presented with a green square), 1 baseline image (presented without squares) and 2 filler images (presented with green squares). Following Mulligan et al. (2014), the target image was always located in the third position, whereas the distractor and baseline images were located either in the first or in the fifth position (the exact position was counterbalanced across blocks). In addition, from 1 to 5 filler images, always presented with green squares, were placed between adjacent blocks to reduce regularity in the appearance of the target squares. Participants were told to pay attention to the images (incidental instructions) and simultaneously press the spacebar whenever they detected a red square.

During the 15-minute interval, participants undertook the four WAIS-IV subtests. Finally, the recognition task involved the presentation of 90 images randomly ordered, comprising 45 old images (presented at encoding: 15 target, 15 distractor and 15 baseline images) and 45 new images (foils). For each image, the instructions were to press the keys “v” or “n” if the participant judged it to be old or new, respectively.

2.3.3. Results

Firstly, we analysed performance at encoding and at test phases independently of the age range.

At encoding, bipolar patients and healthy subjects were found to be equally accurate in the detection of target squares: M (HS)= 90%, M (BP) = 89%, $t(52) = 0.30$, $p = 0.77$; false alarms (i.e., incorrect responses to non-target, green squares) were infrequent but were marginally significant between the two groups: M(HS) = 0.37 vs. M(BP) = 0.93, $t(52) = -1.93$, $p = 0.06$. Mean RTs were numerically, but not significantly, longer for patients ($M = 336$ ms) than for control subjects ($M = 324$ ms), $t(52) = -0.88$, $p = 0.38$.

In the recognition test, groups did not differ in the proportions of false alarms, M (HS) = 0.22 and M(BP) = 0.21, $t(52) = 0.17$, $p = 0.86$. However, to ensure compatibly with results on previous experiment (see Chapter 2.2), statistical analysis was conducted on correct recognition scores (computed as hits – false alarms) (Figure 2.5). Note that the proportions of hits for the stimuli associated to target squares were adjusted by considering only the trials in which participants correctly pressed the spacebar (Rossi-Arnaud et al., 2017; Spataro et al., 2013), also in the next analysis. Scores were submitted to a 2 (Group: healthy control vs bipolar patients) × 3 (Type of Trial: target, distractor and baseline images) mixed ANOVA. The results showed: a) a marginal effects of Trial Type, $F(2, 104) = 2.91$, $p = 0.06$, $\eta_p^2 = 0.05$, with participants recognizing significantly better the baseline picture ($M = 0.52$) that distractor picture ($M = 0.45$, $p = 0.01$); b) a significant main effect of Group, $F(1,52) = 4.13$, $p = 0.05$, $\eta_p^2 = 0.07$, with healthy subjects performing better than bipolar patients ($M = 0.55$ vs. $M = 0.44$); and c) a no significant two-way interaction between Group and Trial Type, $F(2, 104) = 1.20$, $p = 0.30$, $\eta_p^2 = 0.02$.

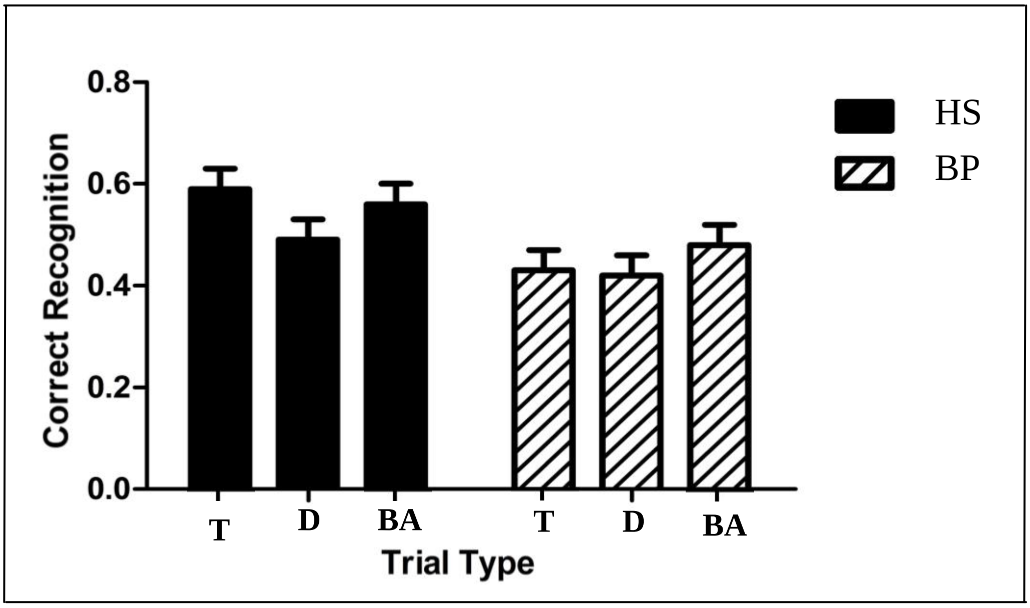

Figure 2.5. Mean proportions of Corrected recognition (hits – false alarms) in healthy subjects (HS) and bipolar patients (BP), as a function of Trial Type. Bars represent standard errors.

Based on previous studies that found a significant effect in a young group of healthy subjects, we wanted to investigate if the absence of the ABE in our control group was influenced by the age. For this reason, we divided both control and patient groups in young-adult participants (range 18-35) and adult participants (range 36-60).

For the range 18-35 years (Young-adults), at encoding, healthy subjects were significantly more accurate in the detection of target squares compared to bipolar patients: *M* (HS)= 99%, *M* (BP) = 90%, $t(21) = 2.54$, $p = 0.03$; false alarms (i.e., incorrect responses to non-target, green squares) were infrequent and not significant between the two groups: *M*(HS) = 0.46 vs. *M*(BP) = 0.50, $t(21) = -0.15$, $p = 0.88$. Mean RTs were numerically, but not significantly, longer for patients (*M* = 329 ms) than for control subjects (*M* = 302 ms), $t(21) = -1.09$, $p = 0.29$.

In the recognition test, the proportions of false alarms differed only marginally between young-adults groups, *M* (HS) = 0.24 and *M*(BP) = 0.16, $t(21) = 0.19$, $p = 0.07$. However, as previously, statistical analysis, here and in the next analysis, were conducted on correct recognition scores (hits – false alarms) (see Figure 2.6). These scores were submitted to a 2 (Group: healthy control vs bipolar patients) × 3 (Type of Trial: target, distractor and baseline images) mixed ANOVA. The results showed: a) no effect of Trial Type, $F(2, 42) = 1.52$, $p = 0.23$, $\eta_p^2 = 0.07$; b) no effect of Group, $F(1,21) = 0.27$, $p = 0.60$, $\eta_p^2 = 0.13$; and, interestingly c) a significant two-way interaction between Group and Trial Type, $F(2, 42) = 5.86$, $p = 0.006$, $\eta_p^2 = 0.22$. A follow-up analysis of simple effects revealed that the effect of Trial Type was significant in young-adult controls, $F(2,20) = 5.23$, $p = 0.01$, $\eta_p^2 = 0.34$. For this group, the recognition of target images (*M* =

0.44) was more accurate than the recognition of distractor (*M* = 0.21, *p* = 0.01) and only marginally than the recognition of baseline (*M* = 0.26, *p* = 0.06) images, which did not differ between them (*p* = 0.99). For young-adult euthymic bipolar patients, the effect of Trial Type was no significant, *F*(2, 20) = 0.98, *p* = 0.39, η_p^2 = 0.09; post-hoc comparisons with the Bonferroni adjustment indicated that older adults recognized with the same accuracy target images (M = 0.21), distractor images (M = 0.26) and baseline images (*M* = 0.32). When analyzed in the opposite direction, this same interaction indicated that the effect of Group was significant in the target condition, with control subjects (*M* = 0.44) outperforming patient subjects (*M* = 0.21), *F*(1, 21) = 5.22, *p* = 0.03, η_p^2 = 0.20; on the other hand, the two groups did not differ in the distractor and baseline conditions, *F*(1, 21) = 0.46, *p* = 0.50, η_p^2 = 0.02 and *F*(1, 21) = 0.44, *p* = 0.51, η_p^2 = 0.02.

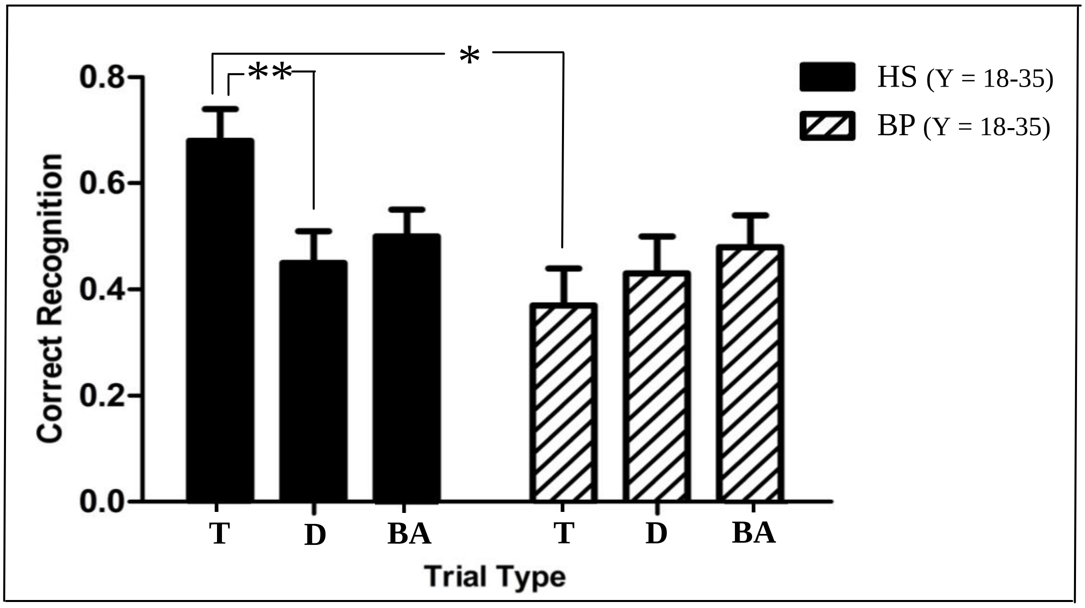

Figure 2.6. Mean proportions of Corrected recognition (hits – false alarms) in young-adult (Y = 18-35 years) healthy subjects (HS) and bipolar patients (BP), as a function of Trial Type. Bars represent standard errors. *: $p < 0.05$; **: $p < 0.01$.

For the range 36-60 (Adults), at encoding, bipolar patients and healthy subjects were equally accurate in the detection of target squares: *M* (HS) = 81% and *M* (BP) = 88%, *t*(29) = -1.04, *p* = 0.31; false alarms (i.e., incorrect responses to non-target, green squares) were significantly different between the two groups: *M*(HS) = 0.29 vs. *M*(BP) = 1.18, *t*(29) = -2.04, *p* = 0.05. Mean RTs were not significantly different between adult patients (*M* = 340 ms) than for control adult subjects (*M* = 344 ms), *t*(29) = -0.24, *p* = 0.81.

In the recognition test, the proportions of false alarms did not differed between adults groups, *M* (HS) = 0.19 and *M*(BP) = 0.24, *t*(29) = -0.99, *p* = 0.33. Corrected recognition scores were submitted to a 2 (Group: healthy control vs bipolar patients) × 3 (Type of Trial: target, distractor and baseline images) mixed ANOVA (Figure 2.7). The results showed: a) no effect of Trial Type, $F(2, 58) = 2.65$, $p = 0.08$, $\eta_p^2 = 0.08$; b) a significant effect of Group, $F(1,29) = 4.76$, $p = 0.04$, $\eta_p^2 = 0.14$, with healthy subjects performing better than bipolar patients ($M = 0.35$ vs. $M = 0.21$); and, interestingly c) no significant two-way interaction between Group and Trial Type, $F(2, 58) = 0.97$, $p = 0.39$, $\eta_p^2 = 0.03$.

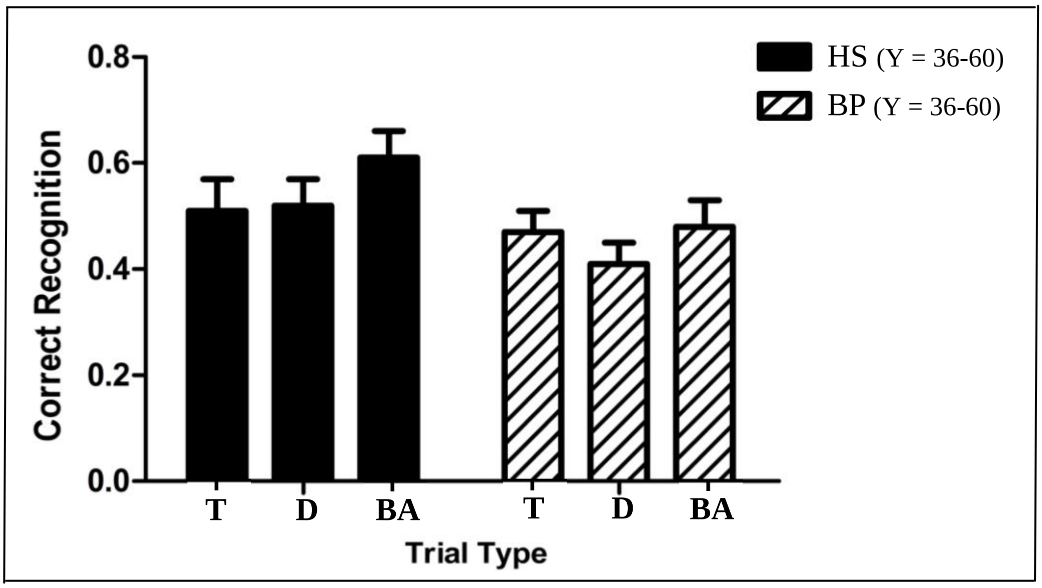

Figure 2.7. Mean proportions of Corrected recognition (hits – false alarms) in adult (Y = 36-60 years) healthy subjects (HS) and bipolar patients (BP), as a function of Trial Type. Bars represent standard errors.

2.3.4. Discussion

In this study, we wanted to investigate the Attentional Boost Effect (ABE) in a sample of bipolar patients in remission phase (euthymic phase). We used a modified paradigm illustrated by Swallow and Jiang (2014). Participants saw a series of pictures with a little square in the center, that could be red or green. In some trial, only the picture was presented, without the square (baseline trials). Participants had to payed attention to the pictures and press the spacebar of the keyboard as quickly as possible every time the red square (target) appeared. No action was requested for the green square (distractors). After a relative brief interval, an old/new recognition test was administered. Results showed no differences between the three conditions in the bipolar group. According, to our hypothesis, patients did not show the facilitation typically observed with the ABE: they did not recognized pictures presented in the target condition (with the red square) better than pictures presented in the distractor condition (with the green square) or in the baseline condition (without any squares). Interestingly, the ABE was absent also in the control group, although they showed a general better performance.

In this experiment we recruited participants from a wide age range, from 18 to 60 years old. Previous experiments on ABE usually investigated the effect in young adults, age range of 18-35 years. Few studies recruited participants with a mean age above 40 years. Among these studies, most part investigated the ABE in patients using a short-term version of the ABE paradigm (Levy-Gigi & Kéri, 2012; Szamosi et al, 2013; Kèri et al., 2013). To our knowledge, only one study used patients matched with ours by age (Rossi-Arnaud et al., 2014). But Rossi-Arnaud et al. (2014) used the first paradigm of the ABE (Swallow & Jiang, 2010), thus results were only partially comparable. For this reason, we divided both our samples (patients and controls groups) in two groups based on the age range. In this way, we defined the young-adult group, range 18-35, and adult group, range 36-59. In the adult range, results showed again the absence of the Attentional Boost Effect (ABE) in both patient and control groups. In the young-adult range, the memory facilitation produced by target detection continued to be abolished only in the patients group. On the contrary, the healthy young-adult controls showed a preserved boost effect: pictures presented with target were significantly better recognized then pictures presented with distractors and then pictures presented without squares, replicating previous results in the literature (Mulligan et al., 2014; Mulligan & Spataro, 2015; Spataro et al., 2013, 2015, 2017; Rossi-Arnaud et al., 2017; Swallow & Jiang, 2010, 2014). Patients performed significantly worse than controls only in the recognition of target images, whereas the two groups were equally accurate in the recognition of distractor and baseline images. As illustrated previously, the ABE represents a trade-off between attentional competition and attentional facilitation (Swallow & Jiang, 2010, 2013). Then, any increase in the attentional requirements of the detection task should result in an impairment in the encoding of target-associated stimuli, and thus a reduction, or even a complete elimination, of the memory facilitation produced by the ABE. In agreement, Swallow & Jiang (2010, Exp.5) showed that enhancing the difficulty of the detection task by requesting different responses to different target items was sufficient to cancel the ABE in young-adults. The results obtained in bipolar patients was comparable with the evidence that an attentional deficit characterized the cognitive profile of these patients, making the detection of target a particularly difficult task. Several evidence indicated that cognitive difficulties characterized this pathology, even in the euthymic phase (Clark et al 2002; Harmer et al 2002; Liu et al 2002; Wilder-Willis et al 2001). More important for our purpose, these patients showed a clear impairment in sustained attention tasks. Typically, a continuous performance task (CPT) was used to measure this function. In general, participant had to monitor a stream of stimuli to detect an infrequent pre-specified target. Several studies indicated that patients were impaired in the detection of the target rather than the rejection of distractor (Clark et al., 2005; Sepede et al., 2012). For example, Sepede et al. (2012) presented visually a series of digits, one per time, to a group of euthymic bipolar patients. Results showed a low level of target accuracy in patients compared to controls, but comparable level of false alarms between groups. The authors found the same results in the group of first-degree relative of these patients. For this reason, they proposed that the impairment in the detection of targets might be a possible trait marker for bipolar patients. In a condition, as the ABE paradigm, where the detection task was emphasizing at the same degree of the primary memory task, the enhanced difficulty of the secondary task should manifest itself as longer RTs or a lower accuracy in the detection of target squares. Our results were in line with this prediction. Indeed, at encoding, RTs were numerically, but not significantly, longer for patients than for control subjects. More important, young-adult patients committed more target missis compered to young-adults control, but the two groups did not differ in the amount of false alarms.

Another possibility was that patients showed a prominent deficit in the inhibitory control. This hypothesis predicts that the advantage of target-associated stimuli should be eliminated because of a selective increase in the recognition of distractor-associated stimuli. If this were the case, we should expect distractor-associated stimuli to be recognized significantly better than baseline stimuli. The result that the two groups did not differ in the false alarms at encoding sit was a first hint that the patients should not had a deficit in the inhibition function. The result in the recognition test were also in line with this conclusion. Swallow & Jiang (2014) suggested that the difference between recognition of baseline and distractor pictures reflected the influence of inhibitory process due to the rejection of distractors on the ABE. In their study, authors concluded that the inhibition mechanisms played a minor role compared to the facilitation effect because there were no differences between the recognition of distractor and baseline images. Our results in young-adults were in line with this conclusion. Both groups did not recognize more pictures encoded with distractors than pictures encoded in the baseline condition.

There results seemed to be in contrast with previous founding of executive difficulties, in particular of an inhibition deficit, in bipolar patients, also in the remission phase (Robinson et al., 2006; Cullen et al., 2016; Palazzo et al., 2017). However, there were evidence according to which euthymic patients could obtain comparable behavioural performances with control subjects in inhibitory tasks. In these work, different pattern of brain activity was found between groups. These results were interpreted as the action of compensatory mechanisms in euthymic bipolar patients (Swann et al., 2013; Morsel et al., 2017; Haldane et al., 2008). For example, Haldane et al., (2008) measure the performance in inhibitory task of euthymic bipolar patients and controls during the acquisition of structural (magnetic resonance - RM) images. Behaviourally results indicated a similar performance between bipolar patients and controls in the inhibitory tasks. Functional results showed that better inhibitory performance in controls correlated positively with grey matter volume in the prefrontal cortical (PFC) regions. In contrast, better inhibitory control in bipolar patients correlated positively with grey matter volume in the right parietal cortical regions. Authors hypothesized that the lack of correlation between PFC grey matter volume and inhibitory control in bipolar patients indicated a prefrontal dysfunction. At the same time, the correlation with the parietal grey matter volume might be indicative of a compensatory role of parietal regions in bipolar disease.

In conclusion, our data were in line with evidence indicating an attentional deficit in bipolar patient, even in the remission phase of the disease. Indeed, the absence of the Attentional Boost Effect seemed to be mediated from the difficulty in the recognition of pictures presented in the target condition. Supporting this interpretation, patients showed also more target misses in the detection task during the encoding phase, indicating that the detection task was more attentional demanding for this group. Suggestive was also the absence of the ABE in the healthy adult control subjects. Considering the results obtained in samples of healthy older adults (above 60 years old), seemed that the facilitatory mechanisms associated with the detection of targets underwent an age-related decrease. Further studies are needed to better understand the nature of this eventual decrease.

2.4. The neural basis of the Attentional Boost Effect

2.4.1. Introduction

Swallow & Jiang (2010) showed a paradoxes phenomenon where images presented with targets (visual or auditory) were better recognized than images presented with distractors. They called this phenomenon Attentional Boost Effect (ABE). According to their interpretation, detecting an occasional target in a secondary task would induce a transient attentional response when the target appears. This attentive orientation response could lead to an increase in the available attentional resources, facilitating the processing of the both target and picture in memory. The authors (Swallow & Jiang, 2010, 2013) hypothesized that the ABE was a compromise between the attentional competition, due to the interference effect of the secondary detection task, and the memory facilitation, due to the transient increase in attention thanks to target detection. When the additional attentional requests needed to detect the target are relatively low, the two effects produce a clear facilitation. As attentive requests for performing the secondary task increase, interference goes beyond facilitation, eliminating the effect (Swallow & Jiang, 2010, Experiment 5). According to Swallow & Jiang (2010), the neural mechanisms involved in increasing attention to the stimuli associated with the targets would be based on a temporary increase in the release of noradrenaline (NE) from the locus coeruleus (LC). When the target was detected, a transient phasic discharge from the LC should enhanced the perceptual process of the contemporary stimuli to the target.

Until now, only one study (Swallow et al., 2012) tried to investigate the brain activity related to the ABE using the functional magnetic resonance imaging (fMRI). The main interest of the authors was to see how the detection of targets influenced activity in regions not involved in processing them. In their experiment, Swallow and colleagues (2012) presented a stream of auditory (Exp. 1) or visual (Exp. 2) stimuli together with images of faces, scenes and scrambled images. Participants were instructed to memorize faces and scenes for a later memory test. They also had to press a button as quickly as possible whenever a pre-specified target occurred. No action was request for distractors. Behavioural results showed the classical Attentional Boost Effect (ABE): a better recognition for pictures presented with target than those presented with distractors. However, the effect found was small (2.8%) relative to previous reports. The functional data from Experiment 1 (auditory detection task) showed an activation of the primary auditory cortex (A1) due to the tones, and it was more strongly activated by targets than distractors. More important, Swallow et al. (2012) found also an activation in the primary visual cortex (V1) that respond more strongly to target tones than to distractor tones. This V1 activation due to targets detection did not differ between the central and the peripheral visual fields represented in the visual cortex and decreased from V1 to the the extrastriate areas (V2 and V3). The authors concluded that the detection of an auditory target produced effects that were not spatially localized and that decreased in magnitude from early to late visual areas (Figure 2.8).

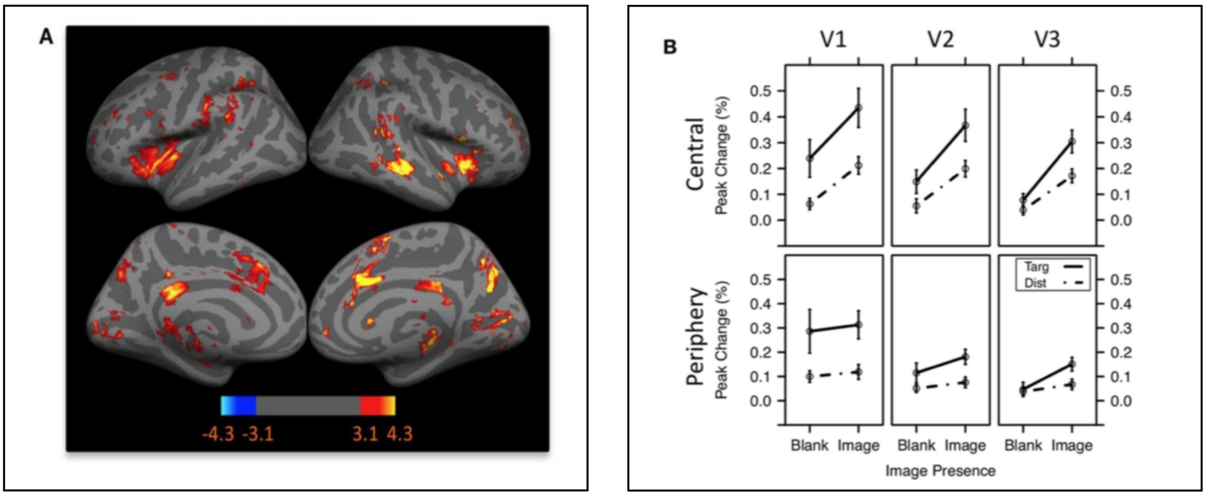

Figure 2.8. (A) Target tones were associated with increased activity in a network of brain regions previously associated with attentional selection. Colour bar values indicate z statistics for the target-distractor contrast. **(B)** Peak percent change in activity in retinotopically defined early visual areas V1, V2, and V3 representing the central and peripheral visual fields following tones. V1 increased more in activity following the presentation of a target tone than a distractor tone (indicated by the difference between the solid and dashed lines). The effect was present in both central and periphery regions, but diminished in magnitude from V1 to V3. Error bars represent ±1 standard error of the mean. Adapted from Swallow et al. (2012).

Similar results were obtained in Experiment 2 (visual detection task): Swallow and colleagues (2012) found an enhanced activation in presence of visual targets relative to distractors not only in the primary visual cortex (V1), in the central and peripheral visual field, but also in the primary auditory cortex (A1). The same pattern of results was obtained even when target and distractor tones were equally frequent (Swallow et al., 2012, Exp. 3). In this case, authors observed, as in Experiment 1, a bigger response of the V1 to targets relative to distractors and the decrease of the effect from V1 to V3. Interestingly, in the Experiment 1 the effect of auditory tones detection on early visual cortical activity was not affected by the concurrent visual encoding task. In some scans participants performed only the auditory detection task, without images presentation. Comparing functional results obtained when pictures were present and when they were not, authors found the same brain activation pattern. The concurrent picture encoding task did not seem to influence the effect of auditory targets on early visual cortical activity. In conclusion, activity of the visual and auditory primary areas seemed to be modulated by the targets detection: the detection of targets, but not the rejection of distractors, boosts activity in perceptual regions of the brain that are not involved in its processing. This effect was not spatially or modality specific (see Makovski et al., 2011, and Swallow & Jiang, 2010, for analogues results from the behavioural point of view) and, surprisingly it was insensitivity to the presence of competing stimuli. The authors referred to this phenomenon as "*target-mediated boost*".

Mulligan & Spataro (2015) hypothesized that the facilitatory effect of the detection of targets took place during an early-phase of the memory encoding. In agreement with the *early-phase-elevated-attention hypothesis* (Criss & Malmberg, 2008; Malmberg & Nelson, 2003), the target detection should enhance processes of stimulus perception and comprehension occurring in the early phases of memory encoding, without involving interpretive elaboration and mental imagery processes occurring in the late phases of memory encoding (Mulligan & Spataro, 2015). Previous data supported this interpretation. Studies with verbal materials (Mulligan et al., 2014; Spataro, Mulligan & Rossi-Arnaud, 2015) showed an intact ABE with high-frequency (HF) and orthographically common words; conversely, the ABE was absent for low-frequency (LF) and orthographically distinctive words. This kind of words attract participants' attention during the early phase of the encoding (Criss & Malmberg, 2008; Malmberg & Nelson, 2003) and are usually remember better than high-frequency and orthographically common words (de Zubicaray et al., 2005; Glanzer & Adams, 1990; Gut- tentag & Carroll, 1997; Marsh et al., 2006). In support of the elevated-attention accounts of word frequency (the superior hit rates for low compared to high frequency words), noteworthy it is the study by de Zubicary et al. (2005). They investigated the word frequency effect recording the BOLD signal during the study of LF and HF words list. The behavioural results showed the classical word frequency effect: participants recognized better LF words than HF words and made more false alarms in the HF condition than in the LF condition. The functional data showed that the coding of the two types of words, correctly recognized at test, differed for the activation of the left inferior prefrontal cortex (LIPC), present only in the LF condition. The activity of this area seemed to be modulated by the effort involved or by the allocation of the attentional resources during encoding (Reber et al., 2002; Wagner et al., 2000), designating it as a plausible area for mediating the increased attentional demand of processing LF words. Based on these data, the authors concluded that the LIPC activation might reflect the greater allocation of attention to the novel features of the LF words compared to those of HF words, supporting the elevated-attention hypothesis of the word frequency effect. Other evidence indicated that low-frequency and orthographically distinctive words are remembered better than high-frequency and orthographically common words when study times are short, and their advantage does not increase with longer encoding durations (Gounden & Nicolas, 2012; Malmberg & Nelson, 2003). In parallel, Mulligan and Spataro (2015) showed that the ABE did not increase when the encoding time was extended from 700 ms to 1500 and 4000 ms; on the contrary, the amplitude of the effect decreased until became no longer significant in the 4-s condition. Based on this evidence, the early-phase-elevated-attention hypothesis explains the absence of the ABE with low-frequency and orthographically distinctive words assuming that the facilitation produced by target detection in the ABE paradigm would be largely redundant with processes that typically happens with these kind of verbal stimuli.

No study of our knowledge has tried to test this hypothesis using pictorial material instead of verbal stimuli. Several functional imaging studies indicated that our visual system is deeply specialized in the processing of different categories of visual stimuli. In the visual pathway, there are specific regions for faces (Kanwisher et al., 1997; Kanwisher & Yovel, 2006), for scenes/building – or in general places (Epstein & Kanwisher, 1998; Ishai et al., 1999), for body parts (Downing et al., 2001), for objects shape (Kanwisher et al., 1997; Grill-Spector, Kourtzi & Kanwisher, 2001) and for words (Baker, Hutchison & Kanwisher, 2007; Cohen et al., 2000). Neuropsychological evidence supported this categorical specialization, showing that the learning and the recognition of different categories can be selectively compromised (i.e., Habib & Sirigu, 1987; Landis et al., 1986; Tippett, L. J., Miller, L. A., & Farah, 2000). However, our ability to recognize stimuli belonging to different categories is not the same between categories. People are in general expert to recognized other people, while relatively few people are specialized in the recognition of particular objects, such as birds, cars, dogs (Carey, 1992; Tanaka & Gauthier, 1997). McKone, Kanwisher & Duchaine (2007) suggested that we have an innate representation of face structure, and that this face template had developed through evolutionary processes, reflecting the extreme social importance of faces. Moreover, Thorpe, Fize, & Marlot (1996) showed that real-world stimuli are recognized more efficiently when they are familiar, a phenomenon that they called "ultra-rapid categorization" (URC). For example, participants can detect the presence of highly familiar stimulus categories (i.e., animals) with a single glance (Thorpe et al., 1996; Li, VanRullen, Koch, & Perona, 2002; VanRullen & Thorpe, 2001a). A possible explanation of this is that familiar stimuli categorization occurs in a pre-attentive manner, with little requirements of top-down control (VanRullen & Thorpe, 2001b; Li et al., 2002; Rousselet, Fabre-Thorpe, & Thorpe, 2002).

In the present study, we used the functional magnetic resonance imaging (fMRI) to investigate the neural correlates of the Attentional Boost Effect (ABE) in healthy subjects. For this purpose, we adapted the behavioural paradigm classically used to investigate the ABE effect to the requirements of the fMRI. As in previous study about ABE (Swallow & Jiang, 2011), first we presented the participants with natural scenes containing a square in the middle, that could be coloured red (i.e., denoting a target stimulus) or green (i.e., denoting a distractor stimulus). The two stimulus types were presented in the same proportion (ratio 1:1). In this encoding phase, participants were instructed to pay attention and memorize every scene. At the same time, they had to detect the red square whenever it was displayed onto the picture. After a 15-minutes interval, a recognition test was administered. In each trials, an old picture (i.e., picture which were presented in the coding phase) or a new picture (i.e., a scene which had never been presented to the subjects) was displayed on the screen. The task of the participants was to indicate if they have seen the picture in the previous task (i.e., encoding phase) or not. The rate of confidence in the answer was also recorded.

First of all, we aimed to investigate the neural determinants of the ABE. According to Swallow & Jiang (2010), the better memory for stimuli co-occurring with target, usually observed in the ABE paradigm, should be a consequence of the facilitation induced by the detection of the target. If this interpretation was corrected, we expected to found enhanced activations in different sensory modality to that used. In particular, we expected to replicate the results obtained by Swallow et al. (2012) showing an activation of the primary auditory cortex (A1) during the visual detection task. They obtained a little behavioural boost effect compared to previous study, as they reported. So we wanted to investigate the brain activation related to the ABE having a broad and strong behaviourally effect.

Moreover, we expected to highlight activation in areas within the frontoparietal ventral network, typically involved in detection tasks (Corbetta, 2002; Corbetta, Patel & Shulman, 2008; Kim, 2014). Corbetta & Shulman (2002) hypothesized the existence of two attentional networks, a dorsal and a ventral attentional networks. The dorsal frontoparietal networks guide the orientation of attention to the selection of the sensory stimuli based on internal goals or expectations and links them to appropriate motor response (it is a goal-driven attention system). The main components of this network are the frontal eye field, the inferior frontal junction, the superior parietal lobule, the medial intraparietal sulcus and the middle temporal area. The ventral frontoparietal network detects salient and behaviourally changes in the environment (it is a stimuli-driven attentional system) and acting as an alerting system for the dorsal network. The main components of this network are the temporoparietal junction (TPJ), the anterior insula, the frontal operculum and the anterior cingulate cortex. Other areas were frequently associated with detection of relevant stimuli, such as sensory cortex and subcortical regions. Sensory cortex was involved to attentive and preattentive modulation of early sensory processing, while subcortical regions might reflect subcortical alerting and other related responses to salient events (see Kim, 20014, for a review).

Finally, the present study was designed to provide additional data to the *early-phase-elevated-attention hypothesis* (Criss & Malmberg, 2008; Malmberg & Nelson, 2003) of the Attentional Boost Effect (ABE) (Mulligan & Spataro, 2015). In particular, we wanted to investigate this hypothesis using pictorial material instead of verbal stimuli. For this specific purpose, we selected pictures of natural scenes containing a semantically relevant object, such a person or a building. No other distinctive element was present in the scenes. In this way, we created two categories of pictures: scenes containing a person and scenes containing a building. This organization allowed us to investigate if the category saliency of pictures influenced the Attentional Boost Effect. We expected a better memory performance for scenes containing person than for scene containing building at the test phase. Persons are distinctive stimuli and they attracted attention automatically (Kanwisher & Duchaine, 2007; Thorpe, Fize, & Marlot, 1996; VanRullen & Thorpe, 2001b), allowing a better memorization. As theorized about the absence of the ABE for low frequency and orthographically distinctive words (Mulligan, Spataro & Picklesimer, 2014; Spataro, Mulligan & Rossi-Arnaud, 2015), the facilitation produced by target detection in the ABE paradigm should be largely redundant with the processing of scenes with person. Then, we expected that the ABE would be greater for scene containing building than for scenes containing person. Importantly, we expect that, during the encoding phase, the coding of the two picture categories will be selectively associated with activation of the Fusiform Face Area (FFA) and the Parahippocampal Place Area (PPA), respectively for scenes containing person and for scenes containing building. Numerous studies indicated that the presentation of people and building (or more in general images of scenes) pictures activated those specific areas in our visual system (Kanwisher et al., 1997; Kanwisher & Yovel, 2006; Epstein & Kanwisher, 1998; Ishai et al., 1999). We hypothesize also that the activity boosted in that very same areas by the simultaneous presentation of the target stimulus. At the end, the literature showed the activation of the left inferior prefrontal cortex (LIPC) in the encoding phase of verbal stimuli with a better recognition in the test phase. As said before, we expected a better memory performance for pictures containing a person than for pictures containing a building. Because there is no evidence of the activation of the LIPC for better remembered pictures, we did not hypothesize to find a specific activation in this area for boosted images containing a person than for boosted images containing a building.

2.4.2. Materials and Methods

2.4.2.1. Participants

33 right-handed healthy volunteers ranging in age from 18 to 35 (17 males, mean age = 25.35, *SD* 3.54) were recruited for the current study. Of these, only 24 subjects (13 males, mean age = 25.7, *SD* 3.58) were considered for the analysis. 2 subjects were excluded because of their performance under the two standard deviations from the mean in the target condition; other 7 subjects were excluded for technical problem of the scanner or because they did not match the clinical selection criteria. All the subjects considered had normal or corrected-to-normal vision and were no taking any psychoactive medications. Major systemic, psychiatric, vascular and other neurological illnesses were excluded.

Approval from the Ethical Committee of Santa Lucia Foundation and written informed consent were obtained before study initiation. Participants were paid for their participation in the study.

2.4.2.2. Materials

160 coloured pictures were selected from SUN database (Xiao, Hays, Ehinger, Oliva, & Torralba, 2010) and the Internet. All the pictures represented natural scenes containing a single object from a study-relevant category, half (80) containing a building and half (80) containing a person. All the images had neutral valence, without specific distinctive characteristics. From this initial set, 96 pictures were used as images in the encoding phase, with the same number of pictures from the two categories. Within each category, 24 pictures were presented with a red square (target condition), and 24 picture were presented with a green square (distractor condition). The assignment of the image to target or distractor condition was randomized for each participant. A further set of 64 images were used as practice items (16 images) at the beginning of the experiment and as *foils* (48 images) in the recognition task. Each picture had 600x800 px dimension and was presented on black background.

2.4.2.3. Procedure

After a brief behavioural training session outside the scanner, participants completed the procedure during the concurrent acquisition of functional magnetic resonance images (fMRI). Participants laid in the scanner in a dimly lit environment. All visual stimuli were projected onto a translucent screen at the back of the MR bore and were visible through a mirror mounted on the head coil. The fMRI experiment included two phases: 1) Encoding phase and 2) Test phase (Figure 2.9).

1) Encoding phase

In the first phase (i.e., encoding phase), participants saw a stream of 96 critical pictures of natural scenes. Half (48) of these pictures represented scenes containing a person, while the other half (48) represented scenes containing a building. Every picture was displayed together with a small square (38x38 pixels) in its middle, that could be coloured as red (target stimulus) in half of the trials and as green (distractor stimulus) in the remaining part of the trials. Hence, overall 48 pictures were presented with target squares and 48 pictures were presented with distractor squares. The task of the participants was to memorize every picture and detect the red square at the same time. Target detection was indicated via speeded, index (or middle finger) press using a two-button MRI-compatible response box. All participants responded with their right hand.

As shown in Figure 2.9 A & B, in each trial, a picture was displayed together with the square for 100 ms. After this time, the image alone remained visible for additional 400 ms. A black display was presented for 1500 ms in which the keypress was recorded, and was followed by an inter trial interval (ITI) ranging between 2000-3000 ms. Every trial was preceded by a 500msec-long fixation (i.e., a cross in the centre of the screen, see Figure 2.9 A & B), and lasted about 5 sec. The pictures presentation was randomized for every participant, with the constrain that no more than three target or distractor trials could be presented in a row, irrespective of the category.

2) Test phase

After 15-minute interval, in which the anatomical scan was acquired, the participants were administrated with an old-new a recognition task (test phases). In this phase, the old pictures (i.e., a picture that was previously presented in the encoding phase) were presented intermixed with 48 new pictures (*foils*) in a randomized order. Given this combination of pictures, we classified all the trials in the test phase in three different conditions: old target pictures (pictures of the encoding phase associated with a red square), old distractor pictures (pictures presented at encoding with a green square) and new pictures (pictures never seen before - *foils*). The trials were further classified as a function of the category (i.e., people vs building, see below in the Analysis Section). In each trial, participants were asked to decide if they had previously seen the picture in the encoding phase or not ("yes" or "no"). In addition, they were required to express the level of their confidence in the previous answer ("very sure" or "uncertain") on the two-button MRI-compatible response box. All subjects responded with their right-hand. More precisely, each trial consisted of a) the presentation of the scene (i.e. Old or New) for 1000 ms, b) the prompt for recognition response ("have you ever seen this picture?" - index finger for "yes", middle finger for "no") and c) the prompt for the expression of the certainty ("How much are you sure?" - index finger for "very sure", middle finger for “uncertain”) Each prompt display was presented for 2000 msec each. The inter trial interval (ITI) ranged from 3000 to 4000 msec (see Figure 2.9 C). Every trial lasted about 10 sec. The test phase was splitted into two runs of about 12 minutes each. The proportion of pictures for each condition (old target, old distractor and new condition) and category (person and building) was counterbalanced between sessions.

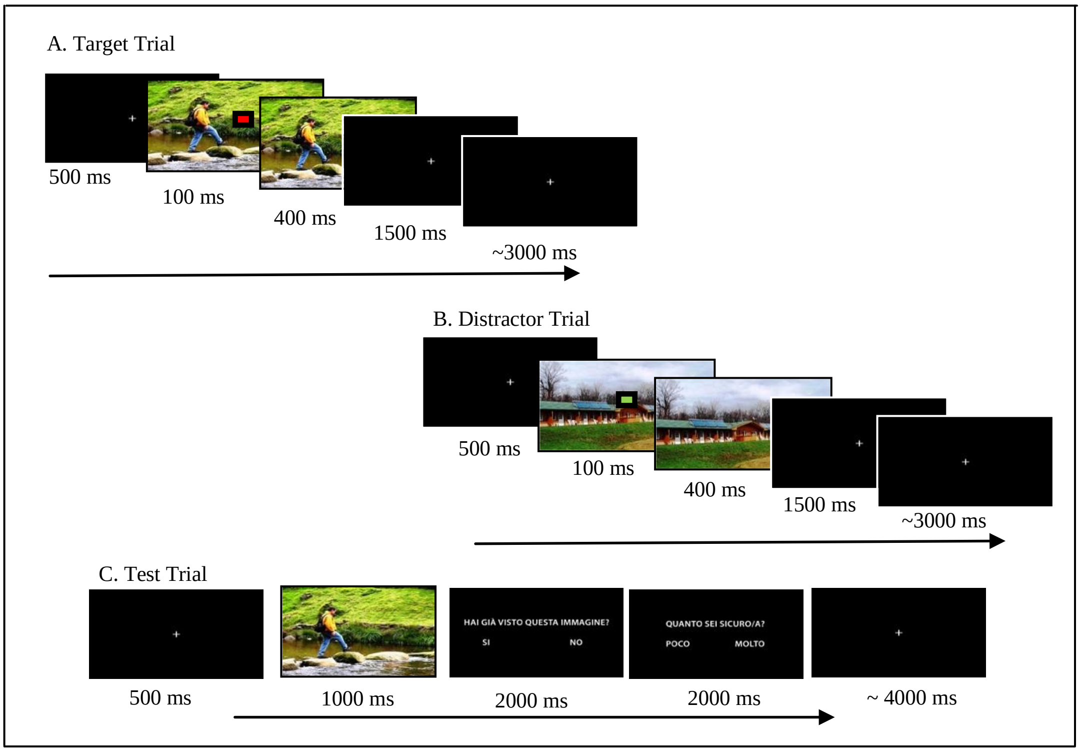

Figure 2.9 A & B) Examples of the Target (A) and Distractor (B) trials in the Encoding phase: participants saw a stream of pictures associated with a little square, that could be red (target) or green (distractor). The instructions were to memorize every picture and press a key as fast as possible when the red square appeared. **C)** Example of a Test trial in the Test phase: participants saw a new stream of pictures, some of them was presented in the encoding phase (old pictures), others were never seen (new pictures). Participant had to indicate if the picture presented was seen before and how sure was about the recognition answer.

2.4.2.4. fMRI images acquisition and Pre-Processing

Functional images were acquired with an Allegra scanner operating at 3 T (Siemens, Erlangen, Germany). BOLD contrast was obtained using echo-planar T2*weighted imaging (EPI). The acquisition of 32 transverse slices (2.5 mm thick, 50% distance factor), with an effective repetition time of 2.08 sec, provided coverage of the whole cerebral cortex. The in-plane resolution was 33 mm. All participants underwent three separate echo-planar- imaging (EPI) scanning runs for the encoding phase (1 run) and for the test phase (separate in 2 runs). The encoding run contained 245 volumes and lasted 8 min, while each session of the test phase contained 360 volumes and lasted 12 min each. During the interval phase, a high-resolution T1- weighted anatomic MDEFT image was acquired for the whole brain.

fMRI data were processed with SPM12 (www.fil.ion. ucl.ac.uk). The first four image volumes of each run were discarded to allow for stabilization of longitudinal magnetization. For each participant, the remaining volumes were realigned with the first volume and the acquisition timing was corrected using the middle slice as reference (Henson, Büchel, Josephs, & Friston, 1999). To allow inter-subject analyses, all images were normalized to the Montreal Neurological Institute standard space (Collins, Neelin, Peters, & Evans, 1994), using the mean of all functional images. All images were smoothed using an isotropic Gaussian kernel (full width at half maximum = 10 mm).

2.4.2.5. Data Analysis

2.4.2.5.1. Boost analysis

To analyse the effect of the memory boost operated by the detection of targets in the pictures (the Attentional Boost Effect), we performed an analysis considering only the trials of the encoding phase. In particular, to disentangle the effect of the Attentional Boost from that more general effect of the encoding of the stimuli, we performed this analysis only on those trials which were correctly recognised in the subsequent test phase (N = 1472).

Statistical inference was based on a random effects approach (Penny & Holmes, 2003). This was composed of two steps. First, for each participant, data were best-fitted (least square fit) at every voxel using a linear combination of the effects of interest. These were the onsets of the stimulus presentation (i.e., when the picture and the square appeared together). We considered in the encoding phase only those trials that were correctly recognized with a high level of confidence in the later test phase. We considered the following event-types: 1) Target pictures containing a person which were correctly recognized in the test phase (TpR); 2) Distractor pictures containing a person which were correctly recognized in the test phase (DpR), 3) Target pictures containing a building which were correctly recognized in the test phase (TbR), 4) Distractor pictures containing a building which were correctly recognized in the test phase (DbR). Trials which missed the criteria of inclusions (i.e., trials presented at encoding and not recognized at test, misses and false alarms at encoding) were also regressed in the model. These additional effects were not considered further in the group-analysis. In addition, the model included regressors modelling the six head movement parameters estimated during realignment. All event types were convolved with the SPM12 standard hemodynamic response function. Linear compounds (contrasts) were used to determine the effect of the four critical conditions. The corresponding 4 contrast images (per participant) were entered in a repeated-measures- ANOVA for statistical inference at the group level. Correction for non sphericity (Friston et al., 2002) was used to account for possible differences in error variance across conditions and any non-independent error terms from repeated measures.

The main analysis aimed at investigating the neural correlates of the attentional boosting operated by target stimulus detection onto the encoding process of images which have been correctly classified on a successive test. To reveal regions involved in the Attentional Boost Effect, we compared the target condition versus the distractor condition (TR > DR, and the opposite DR > TR). Moreover, to see if the boost effect was modulated by the stimulus category, we compared the target condition versus distractor condition in each category (TpR > DpR, and the opposite DpR > TpR; TbR > DbR and the opposite DbR > TbR) and the interaction [(TpR- DpR) + (TbR - DbR)]. To verify if the ABE was modulated by the category salience, we compared the person category versus the building category, independently from the trial type (PR > BR and the opposite BR > PR). The SPM threshold was set to $p < .05$, FWE- corrected at the cluster level (cluster size estimated a *p* uncorrected = .001), considering the whole brain as the volume of interest.

2.4.2.5.2. Encoding analysis

In this analysis we were mostly interested in investigating the general effect of pictures encoding. Critically, this analysis allowed us to examine encoding process during a divide attention condition.

Statistical inference was based on a random effects approach (Penny & Holmes, 2003). This was composed of two steps. First, for each participant, data were best-fitted (least square fit) at every voxel using a linear combination of the effects of interest. These were the onsets of the stimulus (picture and square) presentation in the encoding phase. Based on the organization of the stimuli conditions, trials presented in the encoding phase were classified in the follow way: Target picture with person (Tp), Distractor picture with person (Dp), Target picture with building (Tb), Distractor picture with building (Db). In addition, all error trials (target misses and false alarms at encoding) were modelled as separate event type. Moreover, the model included one regressor modelling the six head movement parameters estimated during realignment. These additional effects were not considered further in the group-analysis. All event types were convolved with the SPM12 standard hemodynamic response function. Linear compounds (contrasts) were used to determine the effect of the four critical conditions. The corresponding 4 contrast images (per participant) were entered in a repeated-measures ANOVA for statistical inference at the group level. Correction for non sphericity (Friston et al., 2002) was used to account for possible differences in error variance across conditions and any non-independent error terms from repeated measures.

This analysis aimed to assessed the combined effect of the detection target squares during the encoding of pictures. To reveal regions involved in this effect, we firstly compared the target condition versus the distractor condition (T > D, and the opposite D > T). Moreover, to statistically evaluate any modulation of the encoding process because of pictures categories, we compared the target condition versus the distractor condition in each category separately (Tp > Dp, and the opposite Dp > Tp; Tb > Db and the opposite Db > Tb) and the interaction [(Tp- Dp) + (Tb - Db)]. We also evaluated the regions involved in the encoding of the two different categories independently from the trial type (P > B, and the opposite B > P), and separately for each trial condition (P > B, Tp > Tb, and the opposite Tb > Tp; Dp > Db and the opposite Db > Dp). The SPM threshold was set to $p < .05$, FWE- corrected at the cluster level (cluster size estimated a p uncorrected = .001), considering the whole brain as the volume of interest.

2.4.2.5.3. Test analysis

In this analysis we were interested to investigate the general effect of pictures recognition. Statistical inference was based on a random effects approach (Penny & Holmes, 2003). This was composed of two steps. First, for each participant, data were best-fitted (least square fit) at every voxel using a linear combination of the effects of interest. These were the correct recognitions in the test phase of the pictures presented in the encoding phase (target and distractor pictures) as “old”, and the correct recognition of pictures never seen before (*foils*) as “new”. Only corrected recognition with high level of confidence were considered in the analysis. Based on the organization of the stimuli in the test phase, trials were classified in the follow way: Target pictures with person correctly recognized (TCp), Distractor pictures with person correctly recognized (DCp), Target pictures with building correctly recognized (TCb), Distractor pictures with building correctly recognized (DCb), New picture with person correctly recognized (NCp), New picture with building correctly recognized (NCb). In addition, the wrong recognition for each category (people and building) and trial type (old – target and distractor – and new) and all error trials (target misses and false alarms at encoding and no answers at test) were modelled as separate event types. Moreover, the model included one regressor modelling the six head movement parameters estimated during realignment. These additional effects were not considered further in the group-analysis. All event types were convolved with the SPM12 standard hemodynamic response function. Linear compounds (contrasts) were used to determine the effect of the four critical conditions, averaged across the two fMRI test runs. The corresponding 6 contrast images (per participant) were entered in a repeated-measure ANOVA for statistical inference at the group level. Correction for non sphericity (Friston et al., 2002) was used to account for possible differences in error variance across conditions and any non-independent error terms from repeated measures.

This analysis aimed to assessed the effect of the recognition test. To reveal regions involved in this effect, we compared "old" pictures (target and distractor) versus "new" pictures (Old > New, and the opposite New > Old). We compared also "old" pictures versus "new" pictures considering each trial condition separately (T > N, and the opposite N > T; D > N, and the opposite D > N). To statistically evaluate any differences because of pictures categories, we compared "old" pictures versus "new" pictures in each category for both trial conditions (Tp > Np, and the opposite Np> Tp; Dp > Np, and the opposite Np > Dp; Tb > Nb, and the opposite Nb > Tb; Db > Nb, and the opposite Nb > Db) and the interactions [(Tp- Tb) + (Np - Nb)] and [(Dp- Db) + (Np - Nb)]. We also evaluated any differences in the regions involved in the recognition of the two trial types comparing target trials versus distractor trials (T > D, and the opposite D > T), considering also each category separately (Tp > Dp, and the opposite Dp > Tp; Tb > Db, and the opposite Db > Tb). The SPM threshold was set to $p < .05$, FWE- corrected at the cluster level (cluster size estimated a *p* uncorrected = .001), considering the whole brain as the volume of interest.

2.4.3. Results

2.4.3.1. Behavioural data

At encoding (see Table 2.7), subjects were very accurate in the detection of target squares, *M* = 99.83 (0.85) %, and there was no difference in the amount of target misses between categories (*M* = 0.04 for building and person categories). They also committed only the 2.26% of false alarms (incorrect responses to non-target, green squares), and there were no differences in the amount of false alarms between categories, *t* (23) = 0.38, *p* = 0.7 (*M* = 0.50 for building category and *M* = 0.58 for person category). The mean Reaction Time (RTs) at encoding was *M* = 448.80 ms (*SD* 102.57 ms).

ENCODING	**Tot**	**Person**	**Building**
Target misses	0.08 (0.41)	0.4 (0.20)	0.4 (0.20)
False alarms	1.08 (0.88)	0.58 (0.65)	0.50 (0.72)

Table 2.7. Means of rough scores for the Target accuracy (target misses and false alarms) in the encoding phase. Total scores (Tot) and scores divided for Category (Person and Building). Standard deviation between brackets.

In the recognition test, subjects committed a low proportions of false alarms (recognition of new pictures as old), $M = 0.23$ (SD 0.08). They committed significantly more false alarms in the building category ($M = 0.30$) than in person category ($M = 0.16$), $t(23) = -4.19$, $p < 0.001$. The means Reaction Time (RTs) for the recognition response was $M = 683.48$ (SD 143.31), and for the confidence response was $M = 546.58$ (SD 140.02).

The proportions of the recognition accuracy based on the level of confidence were show for both categories in Figure 2.10.

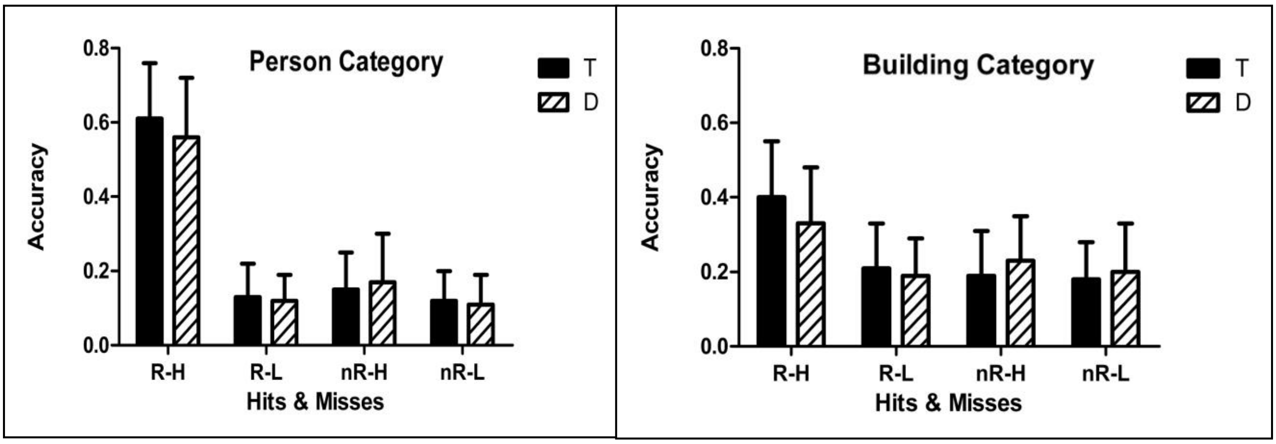

Figure 2.10. Proportion obtained in the test phase (R = Hits, nR = Misses) the base of the Level of confidence (H = high confidence; L = low confidence) of the recognition response for both person and building categories.

Since the proportions of false alarms were significantly different between categories, $t\ (23) = -4.19$, $p < 0.001$ ($M = 0.16$ for person category and $M = 0.30$ for building category), the primary analysis was conducted on corrected recognition scores, computed as the difference between hits and false alarms. These scores were submitted to a two-way mixed ANOVA, with Trial Type (target vs. distractor) and Category (person vs. building) as within independent variables (Figure 2.11). The analysis was corrected for target misses and false alarms at encoding. Results showed a) a significant main effect of Trial Type, $F\ (1,23) = 7.71$, $p = 0.01$, $\eta_p^2 = 0.25$, with target picture (M = 0.44) better recognized than distractor pictures (M = 0.37) – the *Attentional Boost Effect (ABE)*; b) a significant main effect of Category, $F\ (1,23) = 83.99$, $p < 0.001$, $\eta_p^2 = 0.78$, with pictures with person (M = 0.55) better recognized that pictures with building (M = 0.26); c) no significant interaction, indicating that the ABE is significant in both categories.

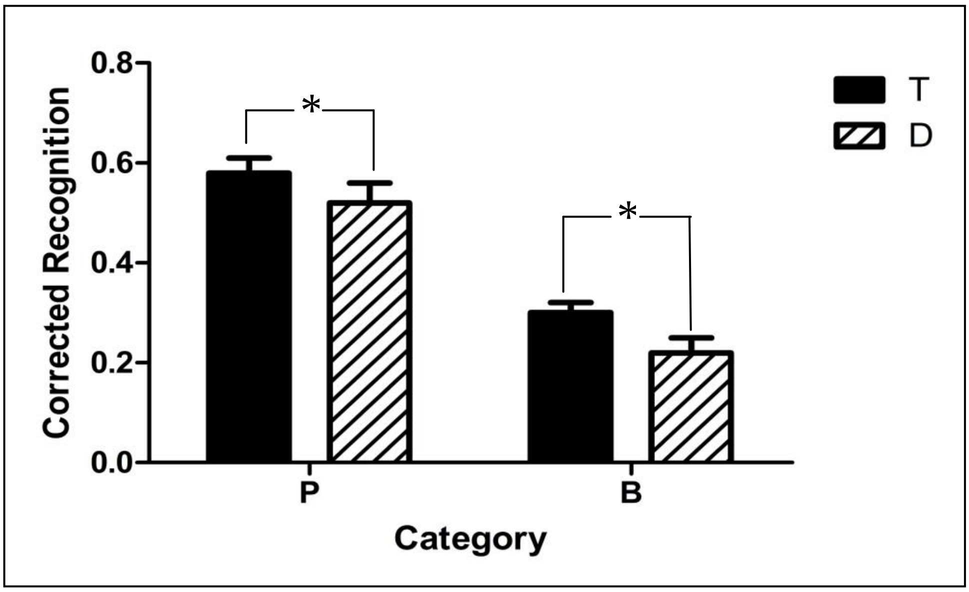

Figure 2.11. Mean proportions of Correct Recognitions for pictures as function of Trial Type (T = Target; D = Distractor) and Category (P = Person; B = Building). *: $p < 0.05$

To ensure the comparability with the fMRI analysis, statistical analyses were conducted considering only scores with high level of certainty to ascertain if the previous pattern was retained. False alarms with high level of recognition (new picture recognized as “old” with high level of confidence) were significantly different between categories, t (23) = -2.88, p = 0.008 (M = 0.06 for person category and M = 0.10 for building category). Because of this significant difference and to ensure comparability with the results of the previous analysis, statistical analyses were again conducted on corrected recognition scores (hits – false alarms) with high level of confidence (Figure 2.12). The analysis was corrected for target misses and false alarms at encoding. The 2 (Trial Type: target vs. distractor) x 2 (Category: person vs. building) mixed ANOVA revealed: a) a significant main effect of Trial Type, F (1,23) = 5.94, p = 0.02, η_p^2 = 0.20, with target picture (M = 0.43) better recognized than distractor pictures (M = 0.36) – the *Attentional Boost Effect (ABE)*; b) a significant main effect of Category, F (1,23) = 136.96, p < 0.001, η_p^2 = 0.86, with pictures with person (M = 0.52) better recognized that pictures with building (M = 0.26); c) no significant interaction, indicating that the ABE did not differ between categories.

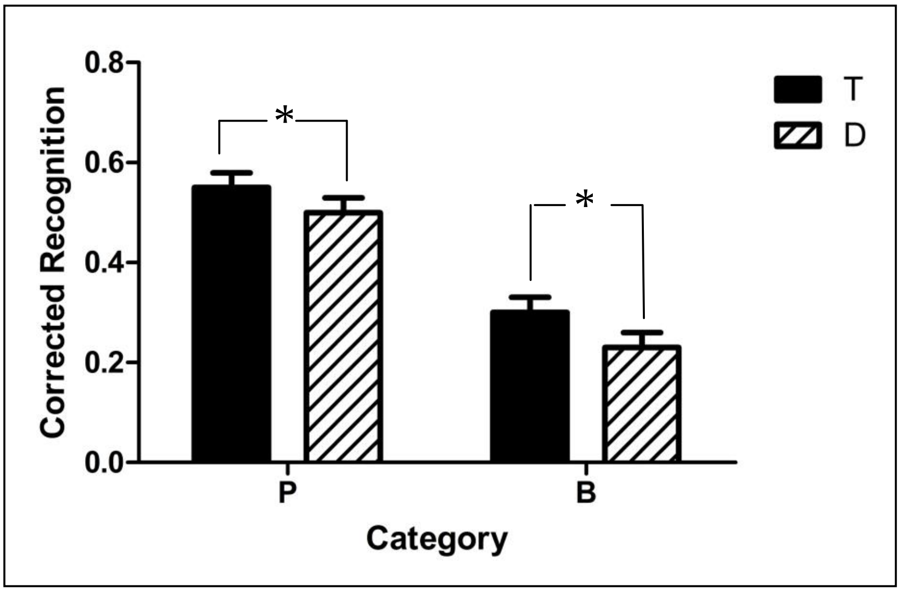

Figure 2.12. Mean proportions of Correct Recognitions with a high level of confidence for the recognition response for pictures as function of Trial Type (T = Target; D = Distractor) and Category (P = Person; B = Building). *: $p < 0.05$

A t-test confirmed that the ABE was present in both categories, with the same amplitude. We run a first analysis considering the difference between hits in target and distractor conditions, independently from the level of confidence for the recognition answer. Although numerically bigger in the building category (M = 0.09) than in the person category (M = 0.06), the amplitude of the effect did not differ between categories, *t* (23) = -0.89, *p* = 0.38. The analysis was conducted also considering only scores with high level of certainty, obtaining same results, M (building) = 0.07, M (person) = 0.05, *t* (23) = -0.49, *p* = 0.63.

2.4.3.2. fMRI analysis

2.4.3.2.1. Attentional Boost analysis

To analyse the effect of the detection of targets during the encoding of pictures on the memory performance (the Attentional Boost Effect), firstly we performed an analysis only on the trial presented in the encoding phase. In particular, to disentangle the effect of the Attentional Boost from that more generic of the encoding of the stimuli, we performed this analysis only on that encoded trials which were correctly recognised in the subsequent test phase. To do this, we compared target condition versus distractor condition (T > D). The target condition highlighted an activation cluster in the parietal lobe which extended frontally into the motor areas and deeper in the cingulate cortex and insula. A second cluster was located posteriorly and included the cerebellum lobes and the worm. A third cluster extended from the frontal operculum medially to the

Insula. The last cluster was founded in the parietal lobe, in the precentral area and moved posteriorly to the supramarginal gyrus. The main effect of the distractor condition was found no significant. (Table 2.8)

To investigate the role of the category in the Boost Effect, we conducted a similar analysis considering each category separately. We firstly compared target condition containing a person versus distractor condition containing a person (Tp > Dp) (see Table 2.8). The analysis revealed two main clusters in the parietal lobe. The first one extended from the supramarginal gyrus onto the primary auditory cortex (Figure 2.13) in the temporal lobe. The second one extended medially to the insula from the postcentral gyrus Moreover, we found four smaller activation clusters located in the cerebellum, in the rolandic operculum, in the cingulate cortex and in the supramarginal gyrus, respectively. We also compared target condition with building versus distractor condition with building (Tb > Db) (Table 2.8). In the parietal lobe, an activation cluster extended frontally to the motor areas and deeper to the insula. Another cluster extended along the lateral sulcus in the rolandic operculum and the supramrginal gyrus. Finally, we found two activation clusters in the rolandic operculum and in the cerebellum. The opposite comparisons (Dp > Tp and Db > Tb) did not reveal any significant activation pattern. Similarly, the interaction term was not significant.

To investigate if the accuracy for the two categories is related to a specific activation, we compared the pictures category independently from the type of the trial. The person category highlight activation clusters in the occipital cortex, the fusiform area, that extended anteriorly in the middle and inferior temporal lobe.

BOOST	cluster	Hem	Coordinates	p-corr	Z value
		T>D			
Parietal Inferior gyrus	10714	L	-56 -24 50	p < 0.001	Inf
Insula		L	-36 -2 12		7.53
Supplementary Motor Area		L	-6 -8 52		6.66
Cingulum		L	-2 4 42		5.65
Supplementary Motor Area		R	2 0 58		5.28
Cerebellum 4-5	3120	R	14 -52 -16	p < 0.001	6.72
Cerebellum 6		R	22 -50 -22		6.27
Vermis 4-5			2 -56 0		4.87
Rolandic Operculum	1541	R	44 0 12	p < 0.001	6.51
Insula		R	42 12 -2		4.76
Postcentral	1422	R	60 -16 20	p < 0.001	6.00
Supramarginal gyrus		R	64 -32 30		5.48
		Tp>Dp			
Postcentral	3727	L	-52 -24 54	p < 0.001	7.18
Primary auditory cortex		L	-56 -34 20		4.98
Supramarginal gyrus		L	-56 -20 20		4.70
Cerebellum 4-5	1581	R	14 -52 -16	p < 0.001	7.03
Cerebellum 6		R	26 -58 -22		4.82
Rolandic Operculum	647	R	44 0 14	p < 0.001	5.95
Insula	969	L	-38 -2 10	p < 0.001	5.74
Cingulum		L	-56 6 20	p = 0.01	4.99
Supramarginal gyrus	324	R	56 -28 42	p = 0.004	4.43
		Tb>Db			
Insula	8869	L	-36 -2 12	p < 0.001	6.49
Parietal Inferior gyrus		L	-56 -22 48		6.30
Postcentral		L	-42 -22 42		6.22

Supplementary Motor Area		L	-6 -10 52		6.15
Precentral		L	-40 -16 54		5.98
Rolandic Operculum	954	R	60 -18 18	p = 0.005	5.21
Supramarginal gyrus		R	52 -36 26		5.17
Cerebellum 6	375	R	44 0 12	p = 0.03	4.77
		PR>BR			
Temporal middle gyrus	1767	R	40 -62 16	p < 0.001	Inf
Temporal inferior gyrus	482	R	42 -46 -20	p < 0.001	Inf
Temporal middle gyrus	870	L	-50 -68 10	p < 0.001	7.36
Fusiform gyrus	192	L	-40 -48 -20	p < 0.001	7.12

Table 2.8. Anatomical location and statistical scores for the regions activated during encoding of pictures that have been correctly recognized with a high level of confidence in the test phase, for each contrast analysed.

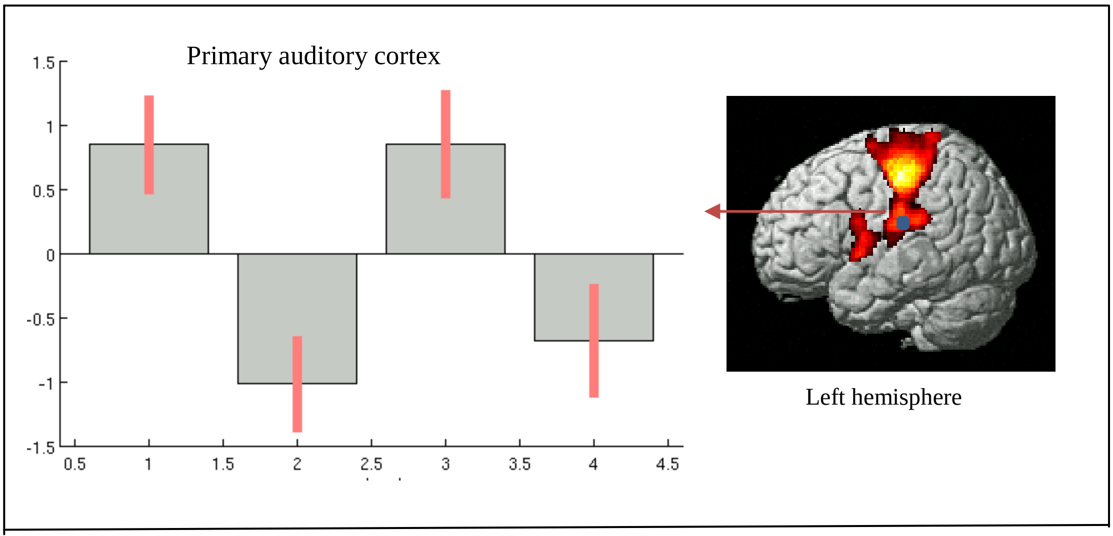

Figure 2.13. Main effect of Target with person condition. Sagittal section and signal plot for the region in the primary auditory cortex (A1). The signal plot shows that the A1 activity is mediated by the target condition. Activations are rendered at p uncorrected = .001(cluster size threshold for the display = 200 voxels).

2.4.3.2.2. *Encoding analysis*

We analysed the general effect of pictures encoding, considering all the encoding trials, independently from the recognition performance. Critically, this analysis allowed us to examine encoding process during a divided attention condition, because the pictures encoding was contemporaneous to a detection task. To do this, firstly we compared target condition versus distractor condition (T > D) (Table 2.9). We found an activation cluster in the parietal lobe that extend frontally to the motor areas, laterally to the superior temporal gyrus and deeply to the cingulate cortex, insula and thalamus. Another cluster was activated posteriorly in the cerebellum. Finally, we found two clusters activated in the frontal middle gyrus and in temporal superior gyrus.

Subsequently, we analysed the effect of the category on the encoding. Then, we compared target condition versus distractor condition in each category (Table 2.9). The effect of the target condition with person (Tp > Dp) highlighted an activation cluster in the parietal lobe that extended frontally in the motor areas, medially in the cingulum and insula and posteriorly in the cerebellum. We found other two clusters in the parietal lobe, in the supramarginal gyrus and in the precuneus. The effect of the target condition with building (Tb > Db) highlighted an activation cluster in the frontal lobe that extended to the temporal superior gyrus through the parietal lobe, and deeper in the thalamus and putamen. Another activation cluster extended from the parietal lobe ventrally to the temporal lobe. We found also two activation clusters in the cerebellum and worm. Another cluster activated in the temporal middle gyrus. Finally, two activation clusters were found in the calcarine scissure both left and right.

ENCODING	**cluster**	**Hem**	**Coordinates**	**p-corr**	**Z value**
			T>D		
Postcentral	30033	L	-42 -22 48	p < 0.001	Inf
Parietal Inferior gyrus		L	-54 -22 50		Inf
Supramarginal gyrus		L	-56 -20 20		Inf
Insula		L	-36 -2 8		Inf
Supplemetary Motor Area		L	-2 -8 52		Inf
Precentral		L	-34 -14 66		7.48
Cingulum		L	-4 6 42		7.20
Temporal superior gyrus		L	-52 6 -4		6.83
Thalamus		L	-16 -20 14		6.71
Cerebelum 6	4593	R	22 -50 -24	p < 0.001	Inf
Cerebelum 6		L	-24 -72 -20		6.10
Vermis 6			2 -66 -8		5.82
Vermis 4-5			2 -60 -2		5.73
Frontal middle gyrus	418	L	-42 -38 18	p < 0.001	4.25
Temporal superior gyrus	352	L	-52 -52 0	p < 0.001	4.23

Tp>Dp					
Parietal inferior gyrus	23656	L	-54 -24 50	p < 0.001	Inf
Cerebellum 6		R	22 -50 -24		Inf
Insula		L	-38 -2 10		6.87
Supplementary motor area		R	0 -4 54		6.74
Cingulum		L	-4 6 42		6.20
Supramarginal gyrus		R	46 -30 44	p < 0.001	5.46
Precuneus		L	-10 -72 58	p = 0.002	3.96
Tb>Db					
Precentral	18248	L	-44 -22 46	p < 0.001	Inf
Postcentral		L	-54 -20 48		Inf
Supramarginal gyrus		L	-56 -20 20		7.71
Supplementary motor area		L	-4 -10 52		7.13
Thalamus		L	-14 -20 10		6.70
Temporal superior gyrus		L	-48 4 -4		6.46
Putamen		L	-32 -10 -4		6.25
Cerebellum 6	2041	R	22 -52 -24	p < 0.001	Inf
Vermis 6			6 -60 -18		5.66
Supramarginal gyrus	1976	R	60 -18 20	p < 0.001	5.97
Postcentral		L	56 -18 38		5.35
Temporal superior gyrus		R	58 -38 24		5.21
Cerebellum 6	391	R	-22 -70 -20	p = 0.01	5.07
Calcarine scissure	326	R	20 -62 8	p = 0.002	4.33
Temporal middle gyrus	366	L	-54 -48 10	p = 0.001	4.29
Calcarine scissure	177	L	-10 -74 14	p = 0.04	4.13

Table 2.9. Anatomical location and statistical scores for the regions activated during encoding of pictures in the target condition versus distractor condition, and in the two category conditions.

In the encoding analysis we also investigated regions involved in the encoding of each category, independently from the trial type (Table 2.10). By Comparing person versus building, we found a first activation cluster in the occipital cortex, including the right fusiform gyrus (Figure 2.14), that extended to the temporal middle gyrus. We also found an activation cluster in the temporal lobe, bilaterally. Finally, we found two more activation clusters in the right calcarine scissure and in the left fusiform gyrus (Figure 2.14). The opposite contrast (building versus person) showed an activation cluster in the superior temporal gyrus, and another cluster located in the cingulum. At the end we run the same contrast (person versus building and the opposite) in each trial condition (target and distractors). The main effects of target with person and distractor with person highlighted activation clusters overlapping with which describe in the main effect of person versus building. Similar overlapping was observed between the main effects of target with building and distractor with building and the main effect of building versus person (Table 2.10).

ENCODING	**cluster**	**Hem**	**Coordinates**	**p-corr**	**Z value**
		P>B			

Fusiform gyrus	3210	R	42 -46 -20	p < 0.001	Inf
Occipital middle gyrus		R	40 -42 -20		Inf
Temporal middle gyrus		R	46 -60 14		Inf
Temporal middle gyrus	1342	R	-50 -76 8	p < 0.001	7.76
Temporal middle gyrus		L	-52 -72 6		7.57
Calacarine scissure	891	R	4 -84 6	p = 0.03	4.78
Fusiform gyrus	436	L	-40 -48 -20	p < 0.001	Inf
			B>P		
Cingulum	851	R	2 -28 44	p = 0.004	5.27
Temporal superior gyrus	173	R	54 -22 6	p = 0.04	4.00
			Tp>Tb		
Fusiform gyrus	2277	R	42 -50 -18	p < 0.001	Inf
Occipital middle gyrus		R	48 -74 2		7.49
Temporal middle gyrus		R	46 -60 14		6.84
Occipital middle gyrus	767	L	-50 -76 8	p < 0.001	6.30
Temporal middle gyrus		L	-40 -66 20		5.21
Fusiform gyrus	367	L	-40 -48 -20	p < 0.001	6.74
Calcarine scissure	180	R	6 -80 4	p = 0.03	4.30
			Tb>Tp		
Frontal middle gyrus	258	R	22 46 32	p = 0.007	4.59
Cingulum	444	R	4 -26 34	p < 0.001	4.18
Temporal superior gyrus	199	R	54 -12 4	p = 0.02	3.97
			Dp>Db		
Fusiform gyrus	2786	R	42 -46 -20	p < 0.001	Inf
Temporal middle gyrus		R	46 -60 14		7.62
Occipital middle gyrus		R	48 -74 2		7.22
Occipital middle gyrus	1065	L	-52 -72 6	p < 0.001	6.54
Temporal middle gyrus		L	-40 -64 20		6.05

Fusiform gyrus	261	L	-40 -48 -20	p < 0.001	6.74
		Db>Dp			
Cingulum	169	R	2 -30 44	p = 0.05	4.69

Table 2.10. Anatomical location and statistical scores for the regions activated during encoding of pictures in both categories (person and building).

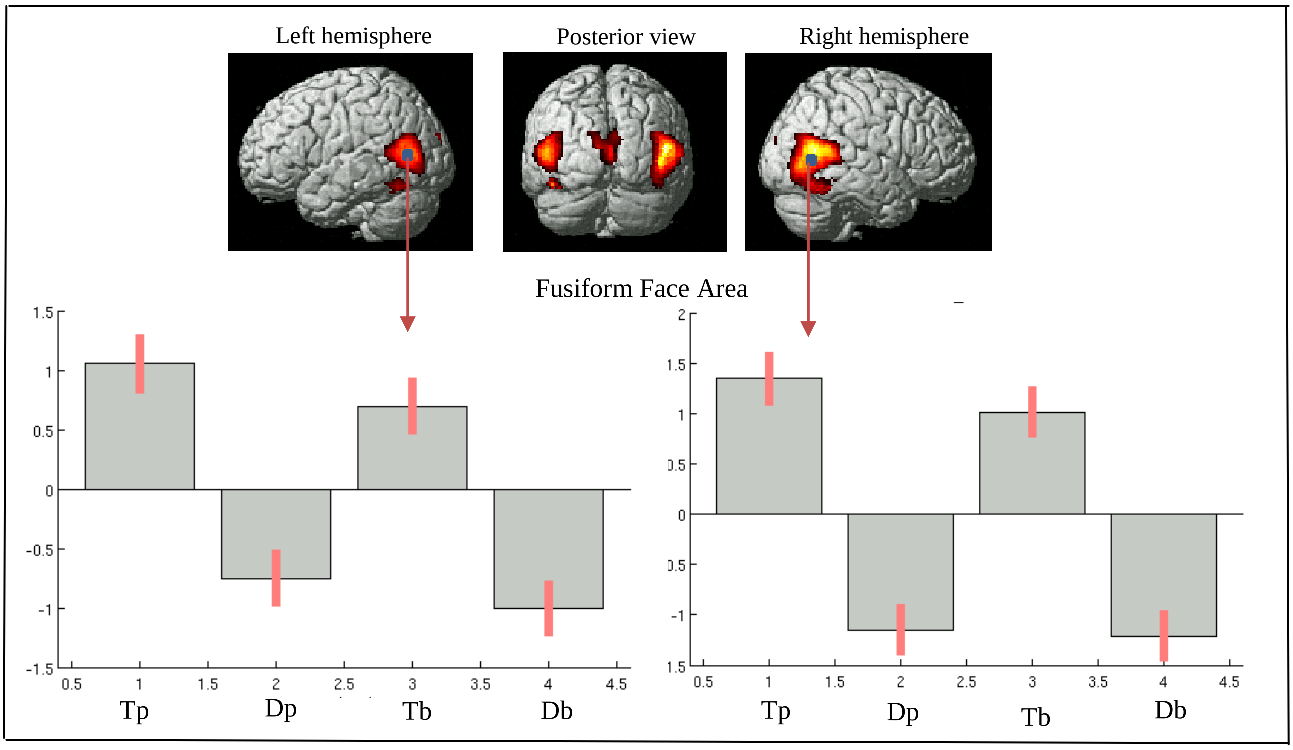

Figure 2.14. Main effect of category. Three-dimensional rendered projections associated with encoding scenes with persons. The signal plots shows that the Fusiform Face Area (FFA) activity in the right and left hemispheres are mediated by the target conditions in both categories. Activations are rendered at p uncorrected = .001(cluster size threshold for the display = 150 voxels).

2.4.3.2.3. Test analysis

In this analysis we wanted to investigate the effect of the correct recognition. To do this, we compared “old” pictures versus “new” pictures (Old > New) (Table 2.11). The old condition highlighted an activation cluster in the occipital lobe the extended deeper in the nucleus caudate. The opposite comparison (New > Old) showed an activation cluster in the frontal lobe that extended dorsally in the parietal lobe until the occipital lobo, in the lingual gyrus. We compared also “old” pictures versus “new” pictures considering each trial condition separately (Table 2.11). Comparing target versus new (T > N), the main effect of target highlighted an activation clusters in the frontal lobe that extended dorsally in the occipital lobe. Comparing distractor versus new (D > N), the main effect of distractors showed a cluster activated in the left cuneus. The opposite comparisons in each trial condition (N > T and N > D) showed activation clusters overlapping to that one activated considering all trials: clusters in the frontal lobe, in the motor areas, that extended in the parietal lobe and in the occipital lobe, in the lingual gyrus.

TEST	**cluster**	**Hem**	**Coordinates**	**p-corr**	**Z value**
		Old>New			
Occipital middle gyrus	268	L	-38 -76 36	p = 0.009	5.02
Caudate	399	R	8 6 -2	p = 0.01	5.02
Cuneus	857	L	-12 -62 22	p = 0.01	4.95
		New>Old			
Postcentral	4387	L	-36 -32 48	p < 0.001	7.34
Precentral		L	-30 -16 60		5.71
Frontal superior gyrus		L	-24 -8 54		5.36
Supplementary motor area		L	-4 8 52		5.16
Supramarginal gyrus		L	-54 -20 38		4.71
Lingual gyrus	1432	L	14 -78 0	p < 0.001	6.79
Postcentral	212	R	40 -28 42	p = 0.04	4.58
Frontal middle gyrus	391	L	-26 46 22	p = 0.003	4.44
Precentral	413	L	30 -4 54	p = 0.002	4.42
		T>N			
Occipital middle gyrus	254	L	-38 -76 36	p = 0.005	5.15
Inferior frontal gyrus	527	L	-32 26 -12	p < 0.001	4.58
Cuneus	627	L	-4 -66 28	p < 0.001	4.54
		N>T			
Postcentral	2263	L	-36 -32 46	p < 0.001	6.89
Frontal superior gyrus		L	-24 -6 56		4.87
Precentral		L	-32 -8 64		4.86

Lingual gyrus	1004	L	14 -76 2	p < 0.001	6.26
D>N					
Cuneus	298	L	-12 -62 24	p = 0.01	4.37
N>D					
Postcentral	3406	L	-36 -32 48	p < 0.001	5.89
Precentral		L	-32 -18 60		5.19
Lingual gyrus	886	R	14 -78 0	p < 0.001	5.53
Frontal middle gyrus	222	L	-26 44 24	p = 0.03	4.14

Table 2.11. Anatomical location and statistical scores for the regions activated during the recognition of pictures in the test phase.

To investigate the effect of the picture category on the recognition, we compared we compared “old” pictures versus “new” pictures in each category for both trial conditions (Table 2.12). The main effect of target with person (Tp > Np) highlighted an activation cluster in the pars orbitalis of the inferior frontal gyrus and another cluster in the precuneus. No other main effects of old pictures were found.

The main effect of the new pictures, in both category, and versus both trial conditions (Np >Tp; Np >Dp; Nb >Tb; Nb > Db) showed overlapping cluster activated in the frontal lobe, in the precentral gyrus and in the frontal superior gyrus, that extended in the parietal lobe, in the postcentral gyrus until the occipital lobe, in the lingual gyrus.

TEST	**cluster**	**Hem**	**Coordinates**	**p-corr**	**Z value**
Tp>Np					
Inferior frontal gyrus	202	L	-32 24 -12	p = 0.05	4.42
Precuneus	220	L	-6 -66 32	p = 0.04	4.41
Np>Tp					
Lingual gyrus	561	R	12 -80 0	p < 0.001	5.70
Postcentral	835	L	-36 -32 46	p = 0.02	5.39
Precentral	233	L	32 -8 58	p = 0.01	4.95
Np>Dp					

Lingual gyrus	506	R	12 -80 -4	p = 0.001	5.42
Postcentral	314	L	-38 -32 46	p = 0.05	4.61
			Nb>Tb		
Postcentral	430	L	-38 -32 48	p = 0.01	4.95
			Nb>Db		
Postcentral	1578	L	-30 -32 48	p = 0.04	4.70
Frontal superior gyrus	471	L	-24 44 22	p = 0.001	4.40

Table 2.12. Anatomical location and statistical scores for the regions activated during the recognition of pictures in the test phase in both categories.

2.4.4. Discussion

The aim of this study was to investigate the neural basis of the Attentional Boost Effect (ABE). In this phenomenon, pictures that are associated with a target stimulus, that require a response, during their encoding are better recognized in a later test than pictures that are encoded with a distractor stimulus, that not require a response.

In our study, we replicated behaviourally the ABE, using a paradigm where target and distractor squares had the same frequency (see Swallow & Jiang, 2012, for previous results): participants recognized with a significantly better accuracy pictures encoded with targets than pictures encoded with distractors. The boost effect obtained was strong and reliable (8%) compared the previous functional study (2.8% by Swallow et al., 2012). In our experiment we were also interested to investigate if the ABE was modulated by the category salience of the stimulus. Previous results (Mulligan & Spataro, 2015), using verbal material, showed that the boost effect was mediated by a facilitation that occur in an early phase of the encoding (the *early-phase-elevated-attention hypothesis*). Indeed, the effect did not increase when the encoding time was extended; instead, the amplitude of the boost decrease until became no significant for the longest trial duration. Moreover, the ABE did not occur for low frequency and orthographically distinctive words (Mulligan, Spataro, & Picklesimer, 2014; Spataro, Mulligan & Rossi-Arnaud, 2015). This kind of words attracts participants' attention during the early phase of the encoding and are usually remember better than high-frequency and orthographically common words (Hunt & Elliot, 1980; MacLeod & Kampe, 1996). Mulligan et al. (2014) and Spataro et al. (2015) data suggested that the facilitation produced by target detection in the ABE paradigm might be largely redundant with processes that typically happens with these kind of verbal stimuli. Overall, these results should indicate that the ABE was mediated by processes that occur early during encoding (Mulligan & Spataro, 2015). To test *the early-phase-elevated-attention hypothesis* of the ABE, using pictures instead of words, we selected two categories of stimuli: scenes containing a person and scenes containing a building. The typical human adult is highly practiced at identifying individual faces, but is poor at discriminating members of other object classes (Carey, 1992; Tanaka & Gauthier, 1997). McKone, Kanwisher & Duchaine (2007) suggested that we have an innate representation of face structure, and that this face template had developed through evolutionary processes, reflecting the extreme social importance of faces. Moreover, previous studies demonstrated that familiar stimuli were recognized faster and more efficiently (the so called "ultra-rapid categorization" phenomenon) (Thorpe, Fize, & Marlot, 1996). Several authors explained this phenomenon suggesting that the familiar stimuli categorization occurred in a pre-attentive manner, with little requirements of top-down control (Li et al., 2002; Rousselet, Fabre-Thorpe, & Thorpe, 2002; VanRullen & Thorpe, 2001b). Based on these evidence, we hypothesized that the ABE should occur for scene with buildings and should be reduced or eliminated for scenes with persons. First of all, in line with our hypothesis, behavioural results showed that participants recognized significantly better pictures containing a person than pictures containing a building. However, contrary to our hypothesis, behaviourally results showed that the ABE was present for both categories with the same amplitude, although numerically greater for scenes with building. These data suggested that persons were processed more efficiently than buildings. But this advantage did not represent the mechanism underlying the ABE.

The functional analysis wanted to investigate the neural basis of the Attentional Boost Effect. To do this, we selected encoding trials that were correctly recognized with a high level of confidence in the test phase. Whereupon, we compared target versus distractor conditions. Results in the Target condition showed an activation pattern typically involved in the detection task (Bledowski et al., 2004; Corbetta et al., 2008; Hon et al. 2009; Duncan, 2010;). Activation clusters appeared in a network that included bilateral insula, right cingulate cortex, bilateral supplementary motor area (SMA), right frontal operculum and right supramarginal gyrus (temporoparietal junction – TPJ). Other activation clusters were located in the cerebellum and in the pre- and postcentral gyrus reflecting probably the right-handed motor response to the task-relevant target stimuli. The activation of the precentral (M1 Broadmann area) likely reflects the motor component of the response, while the postcentral gyrus (S1 Brodmann area) likely reflects the sensomotory process of the motor response. This network was overlapping with the fronto-parietal ventral network (Corbetta & Shulman, 2002; Corbetta et al., 2008) typically involved in the detection of targets. According to Corbetta & Shulman (2002), we can distinguish between two frontoparietal attentional networks, a dorsal and a ventral network, that guide our orienting response to the environmental stimuli. The dorsal frontoparietal networks guide the selection of the sensory stimuli based on internal goals or expectations and links them to appropriate motor response (it is a goal-driven attention system). The ventral frontoparietal network detects salient and behaviourally relevant stimuli in the environment (it is a stimuli-driven attentional system). These two systems interact during perception to determine what stimuli to focus on (Corbetta et al., 2008). The ventral attentional network is typically involved in detection task (Kim, 2014). However, the ventral network is involved not only in the detection of salient stimuli (as can be a rare target between more frequent distractors), but its activity reflects a dynamic interplay between stimulus saliency and internal goals (Corbetta et al., 2008). Indeed, evidence indicated that this system was activated strongly by task-relevant stimuli (typically rare targets) than task-irrelevant stimuli (rare distractors) (see Swallow & Jiang, 2010, for similar results from the behaviourally point of view). Since targets are salient changes in the environment, because usually are rare but most important they require a behaviourally response, then the presentation of a target stimulus should activate the ventral network more strongly than a presentation of a standard stimulus. Our results were in line with this medialization. Only target condition elicited activation clusters in regions typically involved in this attentional network. In line with the behaviourally results, we did not find the interaction, indicating that the ABE was not mediated by the pictures category. Relevant for the early-phase-elevated-attention hypothesis was the study by de Zubicaray et al. (2005). They suggested that the memory advantage of low frequency words on the high frequency words was mediated by the activation during encoding of the left inferior prefrontal cortex (LIPC). This activation should reflect the bigger effort or the most allocation of the attentional resources on the low frequency words. If this is so and if this was true also for pictures, we should found the activation of the LIPC When we compared trials containing person versus pictures containing building correctly recognized, we did not found the activation of this area in the boost analysis. Although it was important to highlight that the activation of the LIPC could be specific for words (Gabrieli et al., 1998; Wagner, Maril and Schacter, 2000; Reber et al., 2002), this data was a further support to our conclusion that in our experiment the ABE was not mediated by the category salience of the pictures. Anyway, we investigated the small effects of target versus distractor considering person and building separately. Results showed a general overlapping with the main analysis: target condition, in both category, activated regions compatible with the ventral frontoparietal network involved in the detection of targets. Interestingly, we found in the main effect of Target with person condition, an activation peak in the superior temporal gyrus, corresponding to the primary auditory area (A1). This activation seemed to be mediated from the presence of the person in the pictures, because it was absent when we analysed the main effect of the building category.

We also analysed the general effect of encoding, considering all encoding trials independently from the performance at the recognition test. Moreover, this analysis allowed us to see the effect of the division of the attention during this phase, because participants encoded picture and simultaneously performed the detection task. Comparing target versus distractor, the activation clusters were mainly located in regions within the ventral frontoparietal network involved in detection of visual stimuli, as discussed above. It is worth noting the increased activity of the middle frontal gyrus, which has been suggested as putative interface of top-down signals for task relevance onto the ventral network (Miller & Choen, 2001). Similar results were obtained when we analysed the contribution of each category separately. In these analysis it was possible observing the ventral network with more details. Indeed, in the target containing building condition emerged the contribution of the primary visual cortex (V1), bilaterally, and the contribution of more subcortical areas, such as putamen and thalamus. Interestingly, when we analysed regions involved in the encoding person, in agreement with our hypothesis, we found the activation of the Fusiform Face Area (FFA). Accordingly, lots of studies suggested that the processing of faces relied on processes distinct from those engaged during processing of other stimuli. Neuroimaging studies identified the FFA as the area specialized in the processing of faces (Kanwisher et al., 1997; Kanwisher & Yovel, 2006). Neuropsychological, behavioural and electrophysiological studies in human supported the role of the FFA (Yin, 1969; Bentin et al., 1996; Jeffreys 1996; Wada & Yamamoto, 2001; Duchaine et al., 2006; Behrmann & Avidan, 2005). For example, Wada & Yamamoto (2001) describe a patient with very selective damage of the right right fusiform and the lateral occipital region that lost the ability to discriminate unfamiliar faces and recognized familiar faces, but retain the ability to recognize non-face objects. When we analysed the opposite comparison (building versus person), we found the activation of the temporal superior gyrus, that seemed specifically related to the encoding of building.

Finally, we analysed the effect of the recognition in the test phase. In this analysis two pattern of activation could be observed. The recognition of old pictures, when analysed overall or in the single trial condition, elicited the activation of a dorsal network that included the inferior frontal gyrus, the cuneus and precuneus in the parietal lobe, the occipital middle gyrus, corresponding to the visual associative areas, and the nucleus caudate subcortically. The activations in the occipital and parietal lobe seemed to be mediated principally by the recognition of target. On the other hand, the correct rejection of new pictures showed activations in the frontal lobe, in the inferior and middle gyrus, that extended to the motor area, where we observed the activation of frontal areas typically involved in the motor response, such as the SMA, the primary motor area and the primary sensory area; but also the frontal middle and superior gyrus and a specific activation of the right lingual gyrus.

In conclusion, we found a robust and significant ABE using a paradigm where targets and distractors had the same frequency. This effect seemed not to be modulated by the category salience of the picture, because it was present in both scenes containing a person and a building. However, the ABE was numerically bigger in this latter condition, although did not reach the statistical significance. When we investigated the specific activation associated with the ABE, we found regions comparable with those involved in a ventral attention network, well-known to be involved in the detection of behaviourally relevant stimuli (as a target). More interestingly, we found the activation of the primary auditory cortex when the pictures boosted containing a person. In agreement with Swallow & Jiang (2012), the detection of targets, in some conditions, seemed to enhance the processing in brain sensory area not directly involved in that task.

3. General discussion

3.1. Introduction

Swallow & Jiang (2010, 2011, 2012) showed that, in a dual-task paradigm, detecting a target improves memory in a subsequent recognition test for those images that appeared at the same time as the target coloured square compared to the images presented together with the distractors. The authors defined this phenomenon as "Attentional Boost Effect" (ABE). They suggested that the ABE represents a dynamic trade-off between:

- an attentional boost: a facilitation of the primary task (the memory task) due to the transient increase in attention thanks to target detection in the secondary task (the detection task);
- and an attentional competition: an interference on the primary task due to the increase in the demand for attentional resources needed to monitor the colour of squares in the secondary task.

When the additional attentional requests needed to detect the target are relatively low (as in the simple detection task), the two effects produce a clear facilitation. As attention requests to perform the secondary task increase, interference goes beyond facilitation, eliminating the effect. In their experiments Swallow & Jiang (2010) showed that the advantage of the target condition was observed across different types of detection tasks (simple oddball detection and feature-conjunction detection). However, it was eliminated when participants ignored the detection task and when responses were arbitrarily mapped to the targets in the detection task (see Swallow & Jiang, 2010, Exp. 3 and 5). Other experiments showed that the ABE can be obtained with different type of materials (pictures – scenes, objects, faces – and words - Swallow & Jiang, 2010, 2011, 2014; Spataro, Mulligan & Rossi-Arnaud, 2013), in different modalities of the detection and memory tasks (visual and auditory tasks – Swallow & Jiang, 2010; Mulligan, Spataro & Picklesimer, 2014). For the effect to occur, target and item need to be temporally (Swallow & Jiang, 2011), but not spatially overlapped (Spataro et al., 2013; Makovski et al., 2011), and participants have to pay attention to both the detection and the memory task (Swallow & Jiang, 2010). The effect can be obtained even if the target is as frequent as the distractor and if participants process the target without making an overt response, for example by silently counting the targets (Swallow & Jiang, 2012). These studies ruled out a number of potential accounts of the effect. The lack of an ABE in the full attention (FA) condition indicates that the effect is not due to the perceptual saliency of the infrequent targets (squares or circles), but rather that these cues (squares or circles) must be processed as targets (e.g., responded to) for the ABE to be produced (Swallow & Jiang, 2010; see also Makovski, Jiang, & Swallow, 2013). Data on ABE are also inconsistent with simple accounts of the Attentional Boost Effect based on attentional cuing, learning of reward-predictive information, and perceptual grouping (Swallow & Jiang, 2012). According to Swallow & Jiang (2010), detecting an occasional target in a secondary task induces a transient attentional response when the target appears. This orientation response could lead to an increase in the available attentional resources, facilitating the processing and encoding of both the primary and the secondary task stimuli (pictures and squares respectively) in memory. The authors hypothesized that this mechanism is based on a transient increase in the release of norepinephrine from the locus coeruleus – a nucleus in the brainstem which has widespread connections with many cortical regions, including the hippocampus and the occipital cortices (Aston-Jones & Cohen, 2005; Nieuwenhuis, Gilzenrat, Holmes, & Cohen, 2005).

This thesis had two parallel aims. On one side, we wanted to further investigate the Attentional Boost Effect and extend behavioural analyses. In particular, we wanted to investigate the presence of the effect in specific populations: healthy older adults and euthymic bipolar patients. On the other side, we wanted to investigate the neural basis of the ABE by recording the performance of the subjects during the acquisition of functional magnetic resonance images (fMRI).

3.2. Behavioural results

Older adults and euthymic bipolar patients share a number of cognitive difficulties, due to the normal aging process or to the psychiatric pathology. A number of studies showed cognitive deficits (Balota et al., 2000; Palazzo et al., 2017) and functional (Spreng et al., 2012; Drevets et al., 1997) and structural (Raz, 2000; Sullivan and Pfefferbaum, 2006; Canales-Rodríguez et al., 2014) brain alterations in these populations. As far as cognitive deficits were concerned, in both populations, memory, attention and executive deficits, in particular inhibition deficits, were reported. In the literature on normal aging, dozens of studies reported that cognitive abilities decline with age (Craik & Jennings, 1992). Cognitive functions that seem to change more during the lifespan were memory (Craik & Bosman, 1992; Zacks et al., 2000), attention (Connelly et al., 1991; Allen et al., 1992) and executive abilities, such as set shifting (Kramer et al., 1999; Cepeda et al., 2001) and inhibition control (Hasher & Zacks, 1988; Healey et al., 2008); also a generally slower processing speed was frequently reported (Salthouse, 1996). In parallel, there was growing evidence suggesting that bipolar patients showed cognitive impairment, also in the euthymic phase.

Interestingly, several meta-analyses (Robinson et al., 2006; Cullen et al., 2016; Palazzo et al., 2017) reported impairments in general cognitive domains overlapping those compromised in healthy aging. Indeed, executive functioning, verbal memory and sustained attention difficulties seemed to be the most consistent finding in this field. Moreover, these deficits were found not only in patients, in psychotic or euthymic phase (Lim et al., 2013; Palazzo et al., 2017), but also in their first-degree relatives (Bora et al., 2009; Arts et al., 2008). Since the effects of medication did not fully account for the cognitive impairments observed, authors suggested that cognitive impairments exhibited in the euthymic phase were trait markers of the disorder (Bora et al., 2009; Arts et al., 2008). Summarizing, in both populations several studies highlighted cognitive deficits in memory, attention, executive functions, in particular set-shifting and inhibitory control, and a general slower processing speed.

In the aging literature, the study of the memory impairment received a great deal of attention. In particular, episodic memory deficits were frequently observed in healthy adults, especially in dual-task conditions (Grady & Craik, 2000), and different hypotheses have been put forward to explain this decrement. One relevant account was the *reduced attentional resources hypothesis*, which suggested that the attentional resources are limited and that this amount is reduced with aging (Craik, 1986; Craik & Byrd, 1982). As a result, demanding cognitive processes (such as encoding and retrieval) deplete a greater proportion of available resources in older than in younger adults. In the same way, the age-related loss of attention resources would impair, in older adults, the ability to perform two simultaneous tasks with the same accuracy observed in younger adults (Craik & Byrd, 1982; Rabinowitz, Craik & Ackerman, 1982). A set of classical experiments using the divided attention (DA) paradigm have consistently demonstrated that the attentional demands of explicit encoding processes are significantly higher in older than in younger adults (Anderson, Craik, & Naveh-Benjamin, 1998; Anderson et al., 2000; Castel & Craik, 2003; Naveh-Benjamin, Craik, Guez, & Kreuger, 2005). According to the *reduced attentional resources hypothesis*, since memory processes are more attention-demanding and since we have a limited amount of attentional resources, fewer attentional resources remain available for the secondary task, resulting in a secondary task performance decrement. Anderson and colleagues (1998), in particular, examined the effects of study-phase DA on free recall, cued recall and recognition. Younger and older participants intentionally studied lists of words presented in the auditory modality while simultaneously performing a four-choice continuous reaction time (RT) task in which they had to detect a target (a white box) appearing in one of four quadrants of the computer screen. The results revealed that DA at encoding impaired memory performance equally for the two age groups; however, secondary task RTs were slowed to a greater extent in older than in younger adults, especially when the instructions emphasized accuracy in the memory test. The authors interpreted these results suggesting that older people could reach a memory performance comparable to that obtained by younger adults, but this implied higher costs in terms of attentional resources. Other researchers have proposed that different mechanisms underlie the episodic memory difficulties experienced by older adults (see paragraph 1.2.5 for a brief review of the literature). More specifically, the *inhibition deficit hypothesis* (Hasher & Zacks, 1988) suggests that aging reduces the ability to inhibit distractor processing (de Fockert, Ramchurn, Van Velzen, Bergström, & Bunce, 2009; Haring et al., 2013; Hasher, Zacks, & May, 1999; Healey, Ngo, & Hasher, 2014). Hasher & Zacks (1988) hypothesized that cognitive control involves both excitatory processes to enhance the activation of task-relevant information and inhibitory processes to suppress the activation of distracting task-irrelevant information. They suggested that aging was characterized by a relative sparing of excitatory mechanisms and an impairment of inhibitory mechanisms. In support of this hypothesis, several studies have shown that older people process more irrelevant information compared to young people (Conelly, Hasher & Zacks, 1991; Carlson et al., 1995). In several studies on the so-called "hyper-binding" effect, younger and older participants were required to perform a selective attention task on pictures, while ignoring superimposed distractor words. When the authors examined the memory for previous distractor words, older adults outperformed younger adults in both explicit and implicit tasks, suggesting less inhibition of these items at encoding (Campbell, Hasher, & Thomas, 2010; Rowe, Valderrama, Hasher, & Lenartowicz, 2006).

Based on the literature on the bipolar disorder, a similar interpretation could be reached. A sustained attention deficit was usually reported in both mood alteration episodes (Clark et al 2001; Hart et al 1998) and remission phase (Clark et al 2002; Harmer et al 2002; Liu et al 2002; Wilder-Willis et al 2001). This deficit was still observed after controlling for mild residual symptomatology (Clark et al 2002) and pharmacological treatment (Thompson et al., 2005; Goswami et al., 2009), and could account for cognitive impairments in other domains (Ferrier et al 1999). For these reasons, it was proposed to consider it as a trait of these patients (Bora et al., 2009). Usually, sustained attention was measured with continuous performance tasks (CPTs). There are different versions of this task, but in general, participants have to monitor a continuous stream of stimuli (i.e., letters or digits) to detect infrequent and non-salient targets. Optimal performance requires an adequate level of arousal (Parasuraman et al 1998), combined with an element of executive control to resist distraction and inhibit responses to stimuli resembling targets (Braver et al. 2002; Manly and Robertson 1997). Several studies reported decreased target sensitivity (omission errors) in various CPT tasks in euthymic patients with bipolar disorder (Bora et al., 2005; Clark et al., 2002; Clark and Goodwin, 2004; Liu et al., 2002; Swann et al., 2003), indicating an impairment in target detection. However, contrary to what usually reported with patients in acute manic episodes (that showed an impulsive responding in this task) (Clark et al 2001; Swann et al 2003), euthymic bipolar patients did not show a tendency to respond more to the stimuli than healthy subjects (they did not commit more false alarms compared to controls). Sepede et al. (2012) investigated sustained attention in euthymic bipolar patients and first-degree relatives, using a continuous performance tasks (CPT). Participants saw a series of digits, one per time, and had to detect a specific digit (i.e., number "8"). Results indicated a low level of target accuracy in both euthymic patients and relatives compared to controls. The two groups did not differ between them. Moreover, they did not commit more false alarms than healthy subjects. Authors suggested that the impairment in the detection of targets might be a possible trait marker for bipolar patients. On the other hand, executive difficulties, in particular inhibitory control deficit, were usually reported in bipolar patients, even in a euthymic state (Robinson et al., 2006; Cullen et al., 2016; Palazzo et al., 2017). Mur et al. (2007) reported low levels of performance in executive function, inhibition and processing speed tasks in a sample of euthymic patients compared to healthy subjects. However, after checking for the pharmacological therapy, only the inhibition impairment remained significant. Moreover, neuroimaging studies indicated an overlap between regions involved in the inhibition ability and regions implicated in the pathophysiology of bipolar disorder (Blumberg et al., 2003; Aron et al., 2003; Rubia et al., 2003), also during the euthymic phase (Townsend et al., 2012). Finally, there are studies where comparable behavioural performances were reported between euthymic patients and controls in inhibitory tasks. Further, these performances corresponded to different patterns of brain activation between groups, measured with EEG (Swann et al., 2013; Morsel et al., 2017) or with magnetic resonance (RM) imaging (Haldane et al., 2008). Authors interpreted their results as indexes of a compensatory mechanism in euthymic bipolar patients.

Turning to the ABE, on the basis of this evidence, we hypothesized that the Attentional Boost Effect should be decreased or eliminated in older adult and euthymic bipolar patient samples. According to an *attentional deficit hypothesis* in these samples, the loss of attentional resources would impair, in older adults and bipolar patients, the ability to perform two tasks simultaneously with the same accuracy observed in healthy younger adults (Craik & Byrd, 1982; Rabinowitz, Craik & Ackerman, 1982; Clark et al., 2005; Sepede et al., 2012). As explained above, according to the interpretation of Swallow & Jiang (2010, 2013), the ABE represents a dynamic trade-off between *attentional competition* (items in the DA distractor condition were recognized worse than FA performance – the typical negative interfering effect of DA on memory encoding) and *attentional boost* (items in the DA target condition were boosted to the level of FA performance). When the additional attentional requests needed to detect the target are relatively low (as in the simple detection task), the two effects produce a clear facilitation. As attentional requests for performing the secondary task increase, interference goes beyond facilitation, eliminating the effect. In support of this claim, Swallow and Jiang (2010, Exp.5) reported that a modest increase in attentional competition during the target detection task was sufficient to eliminate the ABE. We thus expected that the detection task should be more difficult (in terms of cognitive resources) in older adults and patients than in healthy controls. Conversely, according to an *inhibition deficit hypothesis*, the advantage of target-associated stimuli should be eliminated because of a selective increase in the recognition of distractor-associated stimuli. If this were the case, we should expect distractor-associated stimuli to be recognized significantly better than baseline stimuli. However, in both cases, the consequence should be a significant reduction or even the removal of the facilitation effect due to the detection of targets.

In both studies (chapter 2.2 and 2.3) we found the Attentional Boost Effect in the control group of young adults (range 18-35 years). However, we could not replicate the effect in the groups of healthy older adults and euthymic bipolar patients.

When studying the ABE in older adults we manipulated several factors. We used both pictures and words, with brief (500 ms / trial) and long (1000 ms / trial) encoding time, and varying the type of instructions given to the participants (incidental or intentional). In all cases, the results clearly indicated that the memory facilitation produced by target detection was abolished in the group of older adults. More importantly, results indicated that the lower memory accuracy in older subjects was almost entirely driven by age-related differences in the elaboration of the stimuli associated to target squares. Indeed, in almost all experiments, older adults performed significantly worse than younger adults in the recognition of target stimuli, whereas the two groups were equally accurate in the recognition of distractor and baseline stimuli. In the detection task, when the longer encoding time or the explicit instructions (in Exp. 3 and 4) led older adults to give more emphasis to the encoding of the background stimuli, they showed longer RTs and/or lower accuracy rates in the detection of target squares, suggesting an increased difficulty of the secondary task. On the other hand, when the instructions were incidental (in Exp. 1 and 2), older adults appeared to emphasize the detection task more than the encoding task, as indicated by the fact that their performance in the detection task (in terms of RTs and accuracy) resembled that of the younger group. Even in these cases, however, the recognition of target-associated stimuli was significantly worse in older than in young participants, suggesting that the maintenance of a fast and accurate performance in the detection task required more attention resources in the older group even in the absence of behavioral deficits.

Results in the young adult patients (18-35 years) showed a similar pattern: the memory facilitation due to the target detection was abolished in this group. And, again, they differed from the younger control sample only in the target condition, where healthy subjects showed a better memory performance compared to patients; the two groups were equally accurate in the recognition of distractor and baseline stimuli. Then, as for older adults, also in younger bipolar patients the absence of the ABE seemed to be driven by differences in the processing of the stimuli associated to target squares. In the detection task, patients were numerically slower than control subjects, although this difference did not reach the significance. More importantly, they performed more target misses, indicating that the detection task was more attentionally demanding for them; on the contrary, the two groups showed a comparable number of false alarms, suggesting the intact efficiency of the inhibitory control in patients (confirming previous pattern of results reported in the literature: Clark et al., 2005; Sepede et al., 2012).

In conclusion, in agreement with the *attentional deficit hypothesis*, any increase in the attentional requirements of the detection task should result in an impairment in the encoding of target-associated stimuli, and thus a reduction, or even a complete elimination, of the memory facilitation produced by the ABE. According to this hypothesis, Swallow & Jiang (2010, Exp.5) showed that enhancing the difficulty of the detection task by requesting different responses to different target items was sufficient to cancel the ABE in younger adults. Our data from both studies suggested the presence of a prominent attentional deficit in both older adult and young euthymic patient samples. Indeed, the absence of the Attentional Boost Effect seemed to be mediated by the difficulty in the recognition of stimuli presented in the target condition. Supporting this interpretation, younger patients and older adults (in Exp. 3 and 4, paragraph 2.2.4 and 2.2.5 respectively) showed a lower performance (in terms of RTs and accuracy) in the detection task during the encoding phase compared to control subjects, indicating that the detection task was more attention-demanding for this group. Even when the older adults' performance in the detection task (in terms of RTs and accuracy) resembled that of the younger group, however, the recognition of target-associated stimuli was significantly worse in older than in young participants, suggesting that the maintenance of good performance in the detection task required more attention resources in the older group even in the absence of behavioural deficits. The data obtained in younger bipolar patients supported previous findings according to which a specific deficit in the detection task characterized the cognitive profile of these patients, also in a euthymic phase. In the same way, data obtained in the older adults' experiments might therefore suggest that healthy aging is associated with a naturally-occurring increase in the attentional demands of target detection which is sufficient to eliminate the memory facilitation typically observed in the ABE paradigm. Our data were not in line with a prominent inhibitory control deficit in these groups. Swallow & Jiang (2014) suggested that the difference between recognition of baseline and distractor pictures reflected the influence of inhibitory process due to the rejection of distractors on the ABE. In their study, authors concluded that inhibition mechanisms played a minor role compared to the facilitation effect because there were no differences between the recognition of distractor and baseline images. Our results in young-adults in both studies were in line with this conclusion. Both groups did not recognize more pictures encoded with distractors than pictures encoded in the baseline condition.

It is worth highlighting some observations.

The results obtained in young patients were very similar to those obtained in older adults (Exp. 1), when we used visual stimuli. Data from both experiments showed a similar pattern: the performance in the target condition is numerically lower compared to the performance in the distractor condition, and this one is lower compared to performance obtained in the baseline condition (although in the patients' experiment we found a difference between the three trial conditions only numerically, not significant). This observation might suggest that a comparable mechanism underlies the absence of the ABE with visual stimuli in these two samples. It would be interesting to replicate the experiment on bipolar patients using verbal material, using the same materials and procedure presented in Exp.2 with older adults (paragraph 2.2.3). This should allow to compare data with results in older adults presented in this thesis to see if also using verbal stimuli we found an overlapping results pattern.

Moreover, when we investigate the presence of the ABE in bipolar patients, the effect was abolished not only in both patients' sub-groups, but also in the adults' control sample (36-60 years old). To our knowledge, only a previous study investigated the ABE in a sample of psychiatric patients (schizophrenic patients) with the long-term paradigm of the ABE (Rossi-Arnaud et al., 2014). Although they used a different ABE paradigm making impossible a direct comparison with our results, it was interesting that the authors replicated the effect in their healthy control subjects. More interestingly in our opinion, was the observation that the mean ages of Rossi-Arnaud et al. (2014)'s sample and ours seemed to be different. Control subjects from the study by Rossi-Arnaud et al. (2014) had a mean age of about 40 years. Our control subjects had a mean age of about 50 years, making it possible that at that age the facilitation on the memory performance linked to target detection was already compromised. This comparison suggested the presence of an age-related decline of the facilitatory mechanism at the base of the ABE. This hypothesis was in line with older adults’ experiments that suggested the presence of a naturally-occurring increase in the attentional demands of target detection, sufficient to eliminate the memory facilitation typically observed in the ABE paradigm. However, further analysis would be necessary to investigate the decline of the Attentional Boost Effect with age.

Finally, given the presence in the literature of cognitive profiles of cognitive deficit measured in older adults and bipolar patients, in the interpretation of our results, we took into account two alternative explanations. We compared two hypotheses based on the predominance of a specific cognitive deficit, an attentional or an inhibitory control decline. Considering that is not possible (and probably unlikely) to rule out the action of other cognitive difficulties that could be present in our subjects, we wanted to discuss another possible interpretation. In the literature on aging, several hypotheses were proposed to explain the episodic memory impairment usually observed in normal aging. One of these was the *associative deficit hypothesis* (ADH), according to which older people would find difficult to create and recall the links between units of information (Naveh-Benjamin, 2000). Naveh-Benjamin (2000) used procedures that allow the independent assessment of memory for component and for associative information. Many studies since then supported the ADH showing that older adults exhibit a significant decline in associative memory but only a small or no decline in component memory. This pattern of results was shown for different types of items and relationships (Naveh-Benjamin, Guez, Kilb, & Reedy, 2004; Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003; Naveh-Benjamin, 2000), including inter-item relationships (word pairs, picture pairs, name-face pairs, word-font in which it was presented) as well as intra-item relationships (an item and its context - word and the font in which it was presented). In agreement with this hypothesis, the creation or use of these bonds in a memory task was a significant determinant of mnemonic performance in elderly. Turning to the ABE, Mulligan et al. (2014) proposed that the ABE assessed with words is based on the enhancement of the binding between an amodal and abstract word representation and the spatiotemporal context. This form of contextual binding encoding is critical for performance in explicit test of recognition and recall tasks, was hypothesized to be deeply involved in the episodic memory (e.g., Howard, Fotedar, Datey, & Hasselmo, 2005; Polyn, Norman, & Kahana, 2009; Raaijmakers & Shiffrin, 1981), and represent a prominent function of the hippocampus (Howard, Kumaran, Ólafsdóttir, & Spiers, 2011). Several studies provided some evidence in support of this hypothesis. A study with schizophrenic patients (Rossi-Arnaud et al., 2014) showed that the ABE was absent in these patients. Schizophrenia is a pathology associated with deficits in contextual binding processes (Diaz-Asper et al., 2008); moreover, structural and functional abnormalities of the hippocampus have been consistently documented in these patients (Heckers & Konradi, 2010). Results on the ABE with low-frequency (LF) words could also support the possibility that the attentional boost manipulation enhances context binding. Mulligan et al. (2014) showed that the ABE was not present with low frequency words. Thus, whatever facilitation processing accrues to words in the target condition could be redundant with the processing that typically happens with LF words. One advantage for the LF words is better memory for source information and contextual details. This advantage has been linked to the superior recognition memory for LF words (e.g., Guttentag & Carroll, 1994, 1997; Marsh et al., 2006). An associative deficit at the base of the ABE is an interesting hypothesis. But at the moment, there aren't directly evidence that support it. This interpretation needed to be investigated.

3.3. Functional results

Only one previously study investigated how the detection of targets influenced activity in regions not involved in processing them. In their experiment, Swallow and colleagues (2012) presented a stream of auditory (Exp. 1) or visual (Exp.2) stimuli together with images of faces and scenes, or scrambled images. Participants were instructed to memorize faces and scenes for a later memory test. They also had to press a button as quickly as possible whenever a pre-specified target occurred. No action was request for distractors. Their data showed an activation of the primary visual area during the execution of an auditory detection task, that responded more strongly to target than to distractors. They replicated their results using a visual detection task: in this case target detection, and not distractor rejection, was associated to an activation of the primary auditory cortex. Interestingly, these activations were not mediate by the simultaneously encoding task of pictures, because the same pattern of brain activity was observed even when participants performed the detection task without pictures. Swallow et al. (2012) suggested that detection of target enhanced the sensory processing in areas not directly involved in the target elaboration.

As Swallow et al., (2012), we wanted to test the hypothesis of a facilitatory role of the target detection. To do this, we adapted the behavioural paradigm classically used to investigate the ABE effect to the requirements of the fMRI. We used a paradigm version where target and distractor trials had the same frequency at encoding (see paragraph 1.1.5.2 for previous results with this paradigm by Swallow & Jiang, 2011)

According to Swallow & Jiang (2010, 2013), the better memory for stimuli co-occurring with target usually observed in the ABE paradigm should be a consequence of the facilitation induced by the detection of the target. If this interpretation was corrected, we expected to found enhanced activations in different sensory modality to that used, such as the activation of the primary auditory cortex (A1) during the visual detection task.

Moreover, we expected to highlight activation during target detection in areas within the frontoparietal ventral network, typically involved in detection tasks (Corbetta, 2002; Corbetta, Patel & Shulman, 2008; Kim, 2014). This network detects salient and behaviourally changes in the environment (it is a stimuli-driven attentional system) and acting as an alerting system for the dorsal network.

Finally, the present study was designed to provide additional data to the early-phase-elevated-attention hypothesis (Criss & Malmberg, 2008; Malmberg & Nelson, 2003) of the Attentional Boost Effect (ABE) (Mulligan & Spataro, 2015). In particular, we wanted to investigate the early-phase-elevated-attention hypothesis using pictorial material instead of verbal stimuli. For this specific purpose, we selected pictures of natural scenes containing a semantically relevant object, such a person or a building. We expected a better memory performance for scenes containing person than for scene containing building at the test phase. Persons are distinctive stimuli and they attracted attention automatically (Kanwisher & Duchaine, 2007; Thorpe, Fize, & Marlot, 1996; VanRullen & Thorpe, 2001b), allowing a better memorization. As theorized about the absence of the ABE for low frequency and orthographically distinctive words (Mulligan, Spataro & Picklesimer, 2014; Spataro, Mulligan & Rossi-Arnaud, 2015), the facilitation produced by target detection in the ABE paradigm should be largely redundant with the processing of scenes with person. Then, we expected that the ABE would be greater for scene containing building than for scenes containing person. Importantly, we expect that, during the encoding phase, the coding of the two picture categories will be selectively associated with activation of the Fusiform Face Area (FFA) and the Parahippocampal Place Area (PPA), respectively for scenes containing person and for scenes containing building. Numerous studies indicated that the presentation of people and building (or more in general scenes of places) pictures activated those specific areas in our visual system (Kanwisher et al., 1997; Kanwisher & Yovel, 2006; Epstein & Kanwisher, 1998; Ishai et al., 1999). We hypothesize also that the activity boosted in that very same areas by the simultaneous presentation of the target stimulus.

In agreement with our hypothesis, the analysis of the behavioural data showed that scenes containing person were better recognized than scenes presented with distractors. Moreover, we found a robust (8%) Attentional Boost Effect: scenes presented with targets were better recognized than scenes presented with distractors. Contrary to our hypothesis, the effect was present in both categories.

In the functional analysis we, firstly, tried to showed the activation that should mediated the ABE. To do this, we selected encoding trial that were correctly recognized in the test phase. Whereupon, we compared target versus distractor conditions. Results showed in the target condition an activation pattern matching to the frontoparietal ventral network typically involved in the detection of salient and behaviourally changes in the environment (Bledowski et al., 2004; Corbetta et al., 2008; Duncan, 2010; Hon et al. 2009). However, the ventral network is involved not only in the detection of salient stimuli (as can be a rare target between more frequent distractors), but its activity reflects a dynamic interplay between stimulus saliency and internal goals (Corbetta et al., 2008). Indeed, several evidence indicated that this system was activated strongly by task-relevant stimuli (typically rare targets) than task-irrelevant stimuli (rare distractors) (see Swallow & Jiang, 2010, for similar results from the behaviourally point of view).

In agreement with the behaviourally results, we did not find the interaction, indicating that the ABE was not mediated by the pictures category. Anyway, we investigated the small effects of target versus distractor considering person and building separately. Results showed a general overlapping with the main analysis: target condition, in both category, activated regions compatible with the ventral frontoparietal network involved in the detection of targets. Interestingly, we found in the main effect of Target with person condition, an activation peak in the Superior temporal gyrus, corresponding to the primary auditory area (A1). This activation seemed to be mediated from the presence of the person in the pictures, because it was absent when we analysed the main effect of the building category.

We also analysed the general effect of encoding, considering all encoding trials independently from the performance at the recognition test. Moreover, this analysis allowed us to see the effect of the division of the attention during this phase, because participants encoded picture and simultaneously performed the detection task. Comparing target versus distractor, the activation clusters were mainly located in regions within the ventral frontoparietal network involved in detection of visual stimuli, as discussed above. Interestingly, when we analysed regions involved in the encoding person, according to our hypothesis, we found the activation of the Fusiform Face Area (FFA), an area specialized in the processing of (Kanwisher et al., 1997; Kanwisher & Yovel, 2006). When we analysed the opposite comparison (building versus person), we found the activation of the temporal superior gyrus, that seemed specifically related to the encoding of building.

Finally, we analysed the effect of the recognition in the test phase. In this analysis two pattern of activation could be observed. The recognition of old pictures, when analysed overall or in the single trial condition, elicited the activation of a dorsal network that included the inferior frontal gyrus, the cuneus and precuneus in the parietal lobe, the occipital middle gyrus, corresponding to the visual associative areas, and the nucleus caudate subcortically. The activations in the occipital and parietal lobe seemed to be mediated principally by the recognition of target. On the other hand, the correct rejection of new pictures showed activations in the frontal lobe, in the inferior and middle gyrus, that extended to the motor area.

Summarizing, we found a robust and significant ABE using a paradigm where targets and distractors had the same frequency. This effect seemed not to be modulated by the category salience of the picture, because it was present in scenes containing a person and in scenes containing a building. When we investigated the specific activation associated with the ABE, we found regions comparable with those involved in a ventral attention network, well-known to be involved in the detection of behaviourally relevant stimuli (as a target). More interestingly, we found the activation of the primary auditory cortex. In agreement with Swallow & Jiang (2012), the detection of targets enhanced the processing in brain sensory area not directly involved in that task.

3.4. Conclusion

On one hand, we wanted to extend behavioural results about the Attentional Boost effect (ABE) testing the presence of the effect in samples of older adult and bipolar patients in euthymic phase. On the other hand, we wanted to analyse the neural basis of this phenomenon.

Behavioural results showed the elimination of the ABE in both samples of older adults and patients. The absence of the effect seemed to be mediated by the elimination of the facilitatory effect in the target condition. These results were coherent with the hypothesis of a deficit in the detection of targets due to an attentional impairment in these subjects. Another explanatory hypothesis was taking into account, the associative deficit hypothesis, but it is still speculative.

Functional data showed an activation of a ventral attentional network that seemed mediated the ABE. This network is involved in the detection of task-relevant changes in the environment.

Further analysis should investigate a possible alteration of this network in older adults and bipolar patient to verify its role in the ABE.

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