The role of working memory in compulsive checking and OCD: A systematic classification of 58 experimental findings

Ben Harkin and Klaus Kessler

1. Introduction

Despite a large body of research the evidence for memory impairments in OCD is described as mixed at best (Hermans, Engelen, Grouwels, Joos, Lemmens, & Pieters, 2008). For example, there are inconsistent findings regarding a general mnestic deficit (e.g. Tallis, 1997 vs. MacDonald et al., 1997 and McNally and Kohlbeck, 1993), verbal memory (e.g., intact: Henseler, Gruber, Kraft, Krick, Reith, & Falkai, 2008 vs. deficit: Tuna, Tekcan, & Topcuoglu, 2005) and generally affected visuospatial memory (Hermans et al., 2008, Mataix-Cols et al., 1999 and Muller and Roberts, 2005). We attribute this to the traditional pursuit of OCD memory impairment as one of the general capacity and/or domain specific deficits (visuospatial vs. verbal).

In contrast, a body of research indicates a more subtle relationship, with memory impairments secondary to executive dysfunction (Greisberg & McKay, 2003). If a memory task taps into a dysfunctional component of executive functioning, memory impairment will follow (see Table 1). In this understanding, it is executive deficits in conjunction with task requirements that differentiate memory functioning in OCD from controls (Olley, Malhi, & Sachdev, 2007). This review aims at providing a more precise level of explanation based on Baddeley's extended working memory model (2000) that offers an optimal platform for relating executive functions to representations in memory.

Table 1. - Studies reporting executive deficits in OCD.

Study	Test/Task	Executive function	OCD impairment
Head, Bolton, and Hymas (1989)	Wisconsin Card Sorting Test (WCST)	Set-shifting	More perseverative errors
Roh et al. (2005)			
Sanz, Molina, Calcedo, Martin-Loeches, and Rubia (2001)			
Bohne et al. (2005)	WCST	–	Poorer at learning from feedback
Goodwin and Sher (1992)	WCST	–	Completed less categories
Harvey(1987)			
Head et al. (1989)			
Hymas, Lees, Bolton, Epps, and Head (1991)			
Sanz et al. (2001)			
Chamberlain, Blackwell, Fineberg, Robbins, and Sahakian (2006)	Intra-Dimensional/Extra-Dimensional (ID/ED) Task	Selective attention and set-shifting	Stuck in previous attentional set/impaired in switching cognitive set
Purcell et al. (1998a)			
Veale, Sahakian, Owen, and Marks (1996)			
Watkins et al. (2005)			
Elliott, McKenna, Robbins, and Sahakian (1995)			
Fenger et al. (2005)			
Veale et al. (1996)			
Enright and Beech (1993)	Negative priming	Inhibition	Preattentive deficit in cognitive inhibition
Enright, Beech, and Claridge (1995)			
Hoenig, Hochrein, Muller, and Wagner (2002)			
Moritz, Von Muhlenen, Randjbar, Fricke, and Jelinek (2009)	Inhibition of Return (IOR)	Inhibition	Slower RTs when targets preceded with threat stimuli
Harkin and Kessler (in press)	IOR	–	Normal inhibition overcome by attention to threat
Omori et al. (2007)	Stroop Test, Trail Making Test, Go/No Go Task Category Fluency	Inhibition, cognitive flexibility, and multi-tasking	Only checkers (not washers) was inhibition impairments correlated with poor episodic memory
Bannon et al. (2006)	Go/No Go Task Stroop	Selective attention	Deficit (while OCD symptoms were reduced)
Bannon, Gonsalvez, and Croft (2008)			
Kim et al. (2002)	Trail-Making Task (TMT)	Organization	Consistently slower on Part A (organization impairment) and B (set-shifting)
Penades et al. (2005)			
Roh et al. (2005)			
Fenger et al. (2005)	Figural Fluency Task (FFT)	–	Impaired in organizing spatial information

2. A working-memory explanation

Baddeley's original model (1986) included a central executive, phonological loop and visuospatial sketchpad and was deemed separate from long-term memory (LTM). While this simple model explained a range of data (e.g., phonological similarity, word-length effect), it could not account for all experimental phenomena. For example, the visuospatial sketchpad, a capacity limit of 4 units was observed for the maintenance of individual features (colors or orientations) as well as for integrated objects with colors and orientations (Luck & Vogel, 1997). The so-called “binding problem” (e.g., Treisman, 1996) refers to the fact that information presented in visual scenes rarely consists of isolated features. Rather, features pertain to objects, objects to locations, and objects are further embedded into episodes together with a plethora of contextual information. A parallel processing architecture like the human brain needs mechanisms for tracking “what goes with what” in order to generate and maintain bindings between multiple features (Hinton, McClelland, & Rumelhart, 1986). Therefore, accurate memory (WM and LTM) requires the encoding, maintenance and retrieval of bindings between various aspects of a multimodal episode (Allen, Baddeley, & Hitch, 2006). Baddeley (2000), therefore, extended his classic 1986 WM model to include an “episodic buffer” (EB) that allowed for multimodal, temporarily integrated representations and served as an interface with episodic LTM. Based on this development, we proposed (Harkin & Kessler, 2009) that an executive dysfunction (e.g., unsuppressed intrusive thoughts/stimuli) interferes with fragile multimodal bindings in the EB, resulting in the consolidation of affected episodes into WM and LTM.

3. Empirical evidence from subclinical checkers

With these points in mind, our recent experiments (Harkin and Kessler, 2009, Harkin and Kessler, 2011 and Harkin et al., 2011) set out to: (1) engage the EB using stimuli that required multimodal conjunctions between various object features and spatial locations and to (2) hamper EB functionality by confronting high and low checkers with misleading/irresolvable information during the WM retention interval. In Harkin and Kessler (2009), we employed this novel paradigm for the first time. We presented 4 letters (see Fig. 2) randomly in 6 possible locations and asked participants to indicate 4 s later if a test letter was in the correct (50%) or incorrect (50%) location. The novel manipulation that was meant to induce checking was presented as an additional probe between the encoding-set and the actual test letter. This intermediate probe (probe-1) was either resolvable (e.g., “Where was T”) or misleading (e.g., “Where was K”) referring to its presence or absence in the encoding-set, respectively (see Fig. 2). Misleading trials were hypothesized to induce frustrating and unnecessary checking in those with such a predisposition as no correct answer was possible but in order to proceed, suppression of the misleading information and of the urge to check was required.

We defined high and low checking using the checking subscale of the Vancouver Obsessional-Compulsive Inventory (VOCI; Thordarson, Radomsky,Rachman, Shafran, Sawchuk, & Ralph Hakstian, 2004), which tests for an individuals' checking tendencies in terms of time (i.e., “I spend a lot of time every day checking things over and over again”), content (“I repeatedly check that my stove is turned off …” or “… my doors and window are locked”) and general checking (“One of my repeated problem is repeated checking?”). In our experiments we used a median split of the VOCI score to compare a high scoring (high checking) to a low scoring (low checking) group.

Conforming to our expectations, high scoring checkers' memory performance was attenuated compared to low checkers when interfered by misleading information, yet, performance was not statistically different when the distracting intermediate probe was resolvable or absent. Importantly and in agreement with previous findings (e.g., Ciesielski et al., 2007 and Henseler et al., 2008; see Section 5.2.1), this further underpins that there is no general difference in WM capacity per se between high and low checkers.

We extended these experiments in Harkin and Kessler (2011) to include the same 4 letters in 6 locations but with an additional feature dimension (color) in one experiment and a different distractor probe (spatial) in another. Adding color enhanced the memory load in the EB and resulted in overall reduced performance but not in a specifically enhanced deficit for checkers. Thus, we may have induced a greater degree of checking/uncertainty in all participants. This further emphasizes how careful one must consider the requirements of a task in order to obtain a checker-specific performance deficit. Employing a spatial probe as the intermediate distractor, however, had the desired effect regarding a checker-specific deficit, although WM load per se was not increased. We asked which letter had been presented at a particular location where there either had (resolvable) or had not been a letter (misleading). This spatial distractor manipulation boosted group differences, as it tapped into more specific executive deficits of high checkers (i.e., suppression of distraction) while low checkers were not challenged by this modification.

While we reported robust and replicable effects in the aforementioned studies we were aware of the limitations of using letters in locations, as it is unlikely that they evoke a strong emotional response in checkers (see Moritz et al., 2008). Our third series of experiments, therefore, used ecologically valid stimuli in the form of electrical kitchen appliances (Harkin et al., 2011). We presented 4 kitchen appliances in 6 possible locations on a kitchen countertop: two appliances were ‘ON’ and two were ‘OFF.’ Again, we used an intermediate spatial probe asking if the appliance at a cued location had been ‘ON’ or ‘OFF’ (an appliance had either been there = resolvable, or not = misleading). When the primary WM task required remembering the correct location of an appliance we found a very similar pattern of group differences as we previously had with letters, yet, statistically and experimentally more robust (stronger effect sizes with fewer trials) and, most importantly, accompanied by a metacognitive deficit in high checkers, reflected in reduced confidence even when performance was at ceiling and did not differ statistically from the low checking group, i.e., in the baseline condition without a distracting probe.

4. The EBL (Executive-Functioning, Binding Complexity, Memory Load) classification system

Our synthesis so far leads us to conclude that checkers' memory impairment results from a complex interaction between (1) executive dysfunction in encoding organization, multimodal integration, selective attention (inhibition), maintenance control, and set-shifting and (2) the task components of load (e.g., high load, requiring chunking), multimodality (e.g., location + identity + color), distraction (e.g., dual task paradigm), retrieval dimension (e.g., location), and stimulus salience (e.g. electric switches). We proposed that the likely locus where these deficits interact and potentially augment each other is the episodic buffer (EB) and we have reviewed supporting findings and arguments. In conclusion, we further propose that there are etiological and explanatory factors common to OCD, which can be summarized along the following three dimensions that serve as our basis for predicting and classifying WM deficits in compulsive checking and OCD:

1. Executive Function Efficiency (E): Checking (Cha et al., 2008), rumination (Exner, Martin, & Rief, 2009), and disinhibition (Omori et al., 2007) are all associated with poorer memory in OCD, implying that if these impairments of executive function are present or induced by a task then OCD patients will experience a detriment in memory functioning relative to controls. We follow Wolters and Raffone's (2008) tri-partite definition of executive functioning consisting of (1) Attentional Control: top-down selective activation of task-relevant representations and suppression of task-irrelevant stimuli and responses, (2) Maintenance: holding task-relevant information in an active state, and (3) Integration: flexibly bind and manipulate information from multimodal sources, in the service of controlling task execution. Efficient executive functioning can improve performance by reducing outside interference and by selecting mnemonic strategies such as chunking of information based on long-term-memory knowledge (Miller, 1956). In this understanding, OCD memory impairment occurs when: (1) Experimental manipulations aggravate existing impairments in executive functioning which interfere with attention-dependent bindings. For example, when the encoding-set is concordant with OCD symptomatology it may divide attention between threat and encoding (Coles & Heimberg, 2002), which reduces quality of attention to bindings, impairing memory performance. (2) Inappropriate use of executive strategies decreases binding efficiency and/or the overall load of a given memory representation. We will discuss that an inability to appropriately structure and organize stimulus input is typical of OCD (Kuelz, Hohagen, & Voderholzer, 2004).

2. Binding Complexity (B): Binding different (multimodal) features together and maintaining these representations over time impose a challenge that increases with the number of features and their multimodality. We propose that the executive function deficit ‘allows’ distracting information to affect

the fragile complex bindings in OCD. The inherently greater binding complexities of visuospatial tasks (e.g., multiple objects-to-location bindings) are more likely to reveal OCD impairments than verbal tasks. Complex bindings are susceptible to interference and place greater strain upon correct executive control — especially when multimodal bindings are involved (Harkin and Kessler, 2009, Harkin and Kessler, 2011 and Olley et al., 2007). Verbal deficits, however, will occur if the task relies to a similar extent upon the maintenance of complex bindings (e.g. position of letters in space or sequence). This places memory impairment primarily as an outcome of disrupted multimodal bindings and secondarily as one of memory domain. It just so happens that linguistic/verbal material is usually more strongly subserved by LTM concepts (if not artificially scrambled, e.g. non-words), thus, providing semantic/lexical knowledge that facilitates complex bindings. We expect Binding Complexity to play a predominant role during maintenance, when attention is required to ensure veridicality of WM representations over time.

3. Memory Load (L): Assuming that there is no basic capacity issue involved in OCD (e.g., Ciesielski et al., 2007, Harkin and Kessler, 2009, Harkin and Kessler, 2011 and Henseler et al., 2008), performance deficits under high load would crucially depend on executive strategies (van der Wee et al., 2003): An increase in load (i.e., number of chunks to retain) places greater stress upon the correct implementation of organization strategies (chunking), updating, and overall task-management (Smith & Jonides, 1999). Efficient executive control reduces the overall complexity and/or load of a representation that is subsequently maintained in WM. For example, when recalling a sequence of unrelated words, performance drops when the number of words exceeds five or six as it is beyond the functional capacity of the phonological loop. But, if the words create a sentence, then span can reach as high as sixteen, far exceeding loop capacity (Baddeley, Vallar, & Wilson, 1987). Hence, chunking improves efficiency as items are not individually maintained (Miller, 1956). Therefore, verbal tasks that benefit from semantic clustering could reveal OCD impairments as they fail to efficiently chunk and reduce the load of the encoding-set. Memory impairment is not an issue of basic WM capacity (e.g., Harkin & Kessler, 2009) but rather of creating appropriate mnemonic associations and hierarchical groupings using existing knowledge that alleviates the burden on WM (see Ericsson, Chase, & Faloon, 1980). So, while poorer performance is expected for 'everyone' at high loads, we provide an explanation for when and how people with OCD are particularly affected (e.g., van der Wee et al., 2003). In contrast to Binding Complexity we suggest Memory Load to play a predominant role during WM encoding.

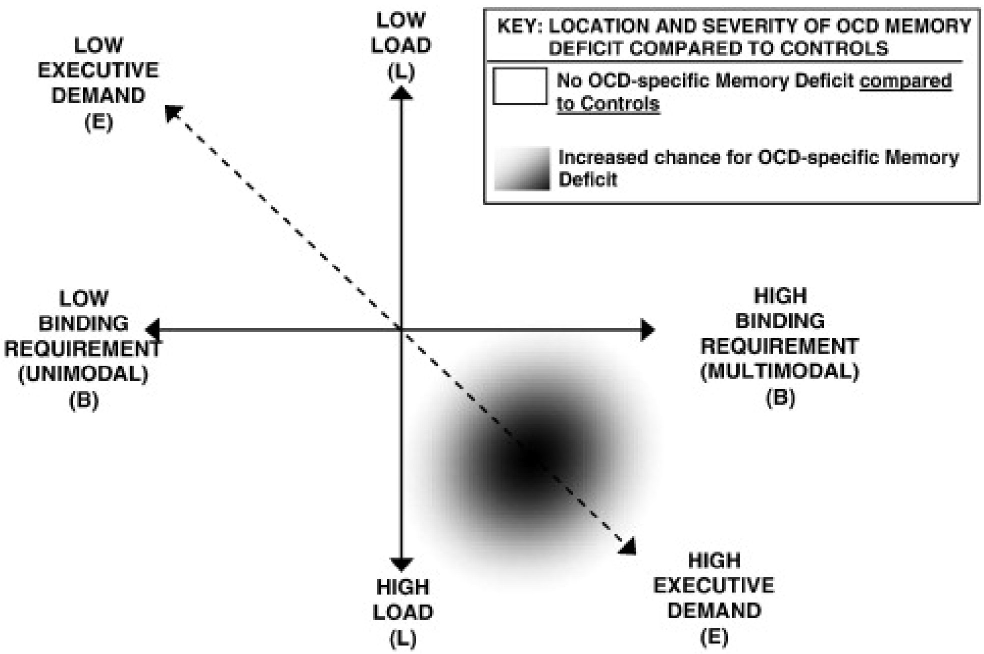
4.1. The role of anxiety in executive function efficiency (E)

In our model (Harkin & Kessler, 2009) as well as in our EBL classification system we focus on the cognitive mechanisms that mediate specific forms of information processing that have been found to be deficient in OCD. We would like to emphasize that the emotional state associated with specific stimuli and situations may boost these deficiencies: Anxiety and lack of confidence in their ability to control a given situation (Rachman, 2002) may further attenuate existent cognitive deficiencies in OCD. In other words, we are careful to state that anxiety/lack of confidence is sufficient but not necessary for executive-memory impairment to occur. For example, we report findings from two studies (see Section 5.2.3.; Rao et al., 2008 and Roh et al., 2005) where resolution of OCD symptoms (and anxiety; Rao et al., 2008) was not associated with improvements in WM functioning. While it could be that some executive deficiencies are part of the OCD endophenotype it is likely that cognitive functions may either become deficient as a consequence of a futile attempt to counteract anxiety by 'over-using' specific executive functions – e.g., memory retrieval may turn into compulsive memory checking (Harkin and Kessler, 2009 and Harkin and Kessler, 2011) – or cognitive functions may become progressively impeded due to constant insecurity fueled by anxiety, manifesting itself as hampered executive selection between stimuli, goals, and actions. Thus, anxiety is likely to act in a manner similar to a dual-task paradigm (Baddeley, 1986) by reducing the amount of attention on the primary memory task. In the following, we implicitly assume a 4th dimension as the level of induced anxiety/insecurity and we propose that this implicit dimension predominantly affects executive functioning and is therefore inherent to the E-dimension of the EBL system. Specifically, we assume that the more threatening the employed stimuli (e.g. switches, electric appliances) or procedures (e.g., pressure, distraction, misleading information) are in a given study, the more likely executive functioning will be modulated, with knock-on effects for memory performance. Paradoxically, memorized threatening items might even improve performance by biasing attention toward these items during encoding.

5. Applying the EBL classification system to 58 experimental findings

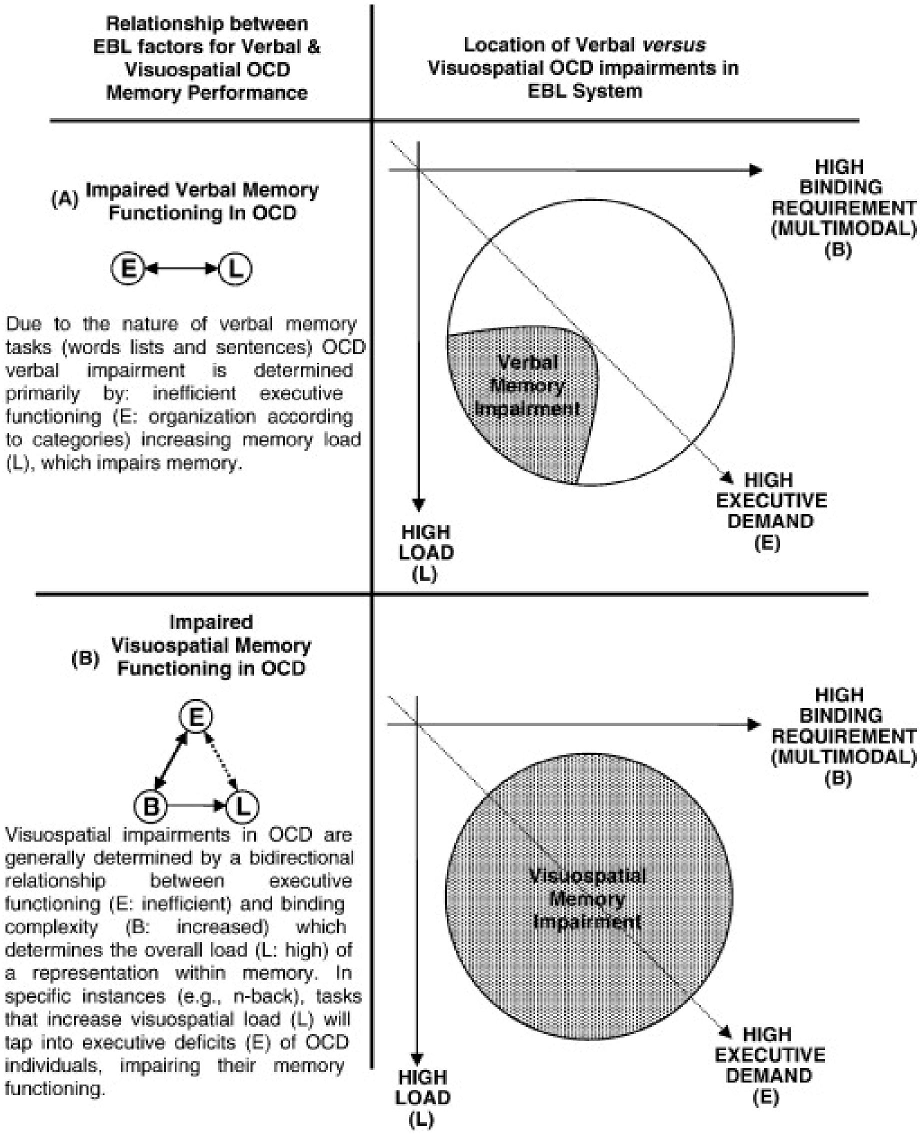
Fig. 1 explains where we do and do not expect to observe OCD memory impairments relative to controls; this we suggest is influenced by the degree of executive function efficiency (E), binding complexity (B) and memory load (L) within any given neuropsychological task. First, we do not expect memory performance to differ between OCD patients and controls for tasks that are low in executive demand, binding and load (see: white region in top-left quadrant of Fig. 1). Second, likelihood for OCD-specific deficits increases as a combination of high load, binding complexity, and executive function requirements (increasingly black area in the bottom-right quadrant). But finally, as we move toward the extreme end of the EBL continuum, memory impairment reduces in magnitude and eventually disappears because controls will be similarly impaired. We suggest that task requirements must be sufficient to tap into executive dysfunction but at the same time not be so extreme to reduce all participants' performance (i.e., controls and OCD) thus obscuring OCD impairments.

Fig. 1. The *EBL* classification system.



In light of this, we suggest that differences in the *EBL* scores of verbal and visuospatial tasks make OCD memory impairments more likely in the latter, especially if spatial locations are relevant to the task. We shall see that verbal tasks, generally, present verbal information in a format (stories, word lists) that is high in load but low in binding complexity. In this case, performance is benefited by efficient executive processes that utilize existing representations in LTM, i.e. chunking according to categories, that reduces load (see Fig. 2A). Thus, verbal impairments in OCD are due to poor executive functioning failing to reduce the load of verbal stimuli and so they operate primarily within the dimensions of E and L. In contrast, visuospatial tasks inherently have a greater binding demand, where successful performance depends on the veridical binding of multimodal features (spatial + visual). Generally, if visuospatial tasks employ multimodal stimuli that cannot be directly linked to a LTM concept (letters or words can) that could support the chunking of WM representations, then memory performance in OCD depends on the bidirectional relationship between executive organization strategies (*E*) and multimodal binding complexity (*B*) which strongly influences the actual load (*L*) of all representations in the EB. In certain instances, tasks that steadily increase load within a visuospatial domain (e.g., *n*-back, corsi-block) will see a detriment in OCD memory performance at higher levels, as it is at this point their executive inefficiencies fail to match task demands, impairing memory relative to controls. In sum, we expect that OCD visuospatial memory impairments will be more evenly distributed between the three *EBL* dimensions as depicted in Fig. 2B. We propose that it is the *EBL* requirement (high scores – but not too high – on all three dimensions) of a task that determines if verbal or visuospatial memory impairments in OCD are observed rather than the domain *per se*.

Fig. 2. - The contribution of *EBL* factors for verbal (A) and visuospatial (B) OCD memory performance and their respective locations of impairment within *EBL* dimensional space.



In the following we will examine studies that investigated OCD memory performance and locate each study's methodology within the EBL classification system. It is important to stress that it is impossible to exactly quantify the ‘scores’ we allocate for a particular study on each dimension. We will explain to the best of our knowledge why there are good reasons to believe that a given study scores highly or lowly on the three EBL dimensions based on its task requirements and by comparing it to other studies. We believe that these virtual scores will help the research community to gain a clear overview of the major findings in the field and allow explaining and predicting under which circumstances memory deficits in OCD do occur and under which they do not. Our analysis will break down the literature into the classic distinction between verbal and visuospatial memory and will discuss for each domain separately why memory functioning remained intact in some studies and then why and which studies did reveal deficits.

5.1. Verbal memory

The literature paints an inconsistent picture with respect to OCD verbal memory performance. We argue that this is due to the manner in which tests of verbal memory differ in their executive-functioning, binding complexity and memory load scores.

5.1.1. Intact verbal memory in OCD

Studies (see Table 2) showing intact verbal memory invariably share the same characteristics: (1) low executive demands (minimal strategy and/or attention allocation necessary), (2) low binding complexity and (3) low memory load, i.e., within phonological loop capacity (6 items). On the other hand, an extremely difficult task that impairs all participants to the same extent is likely to mask any OCD-specific memory impairment.

Table 2. - Studies reporting no verbal memory deficits in OCD.

Authors	Method	Task requirements	Groups compared	Behavioral findings
Henseler et al. (2008)	Delayed match to sample (WM task)	Encode 4 letters, identify if probe letter was in 4	11 OCD patients (YBOCS: 21.0) vs. 11 controls	No differences
Foa et al. (1997)	Sentence recognition	Contamination vs. neutral sentences presented in 3 levels of noise	15 OCD patients (YBOC: 24.7) vs. 15 controls (2.8)	No differences
Martin et al. (1995)	Self-paced word selection task	Always select a different word	18 OCD patients (DSM-III-R criteria) vs. 18 controls	No differences
MacDonald et al. (1997)	Verbal recall and recognition	Memorize 48 words presented for 1 s each	10 OCD checkers (≥ 4 on checking MOCI) and 10 OCD non-checkers (< 4 on checking MOCI) vs. 10 controls	No differences
Rubenstein et al. (1993; Exp. 2)	Verbal recall	Memorize 50 words presented for 4 s each	20 subclinical checkers (≥ 4 checking MOCI) vs. controls (≤ 2)	No differences

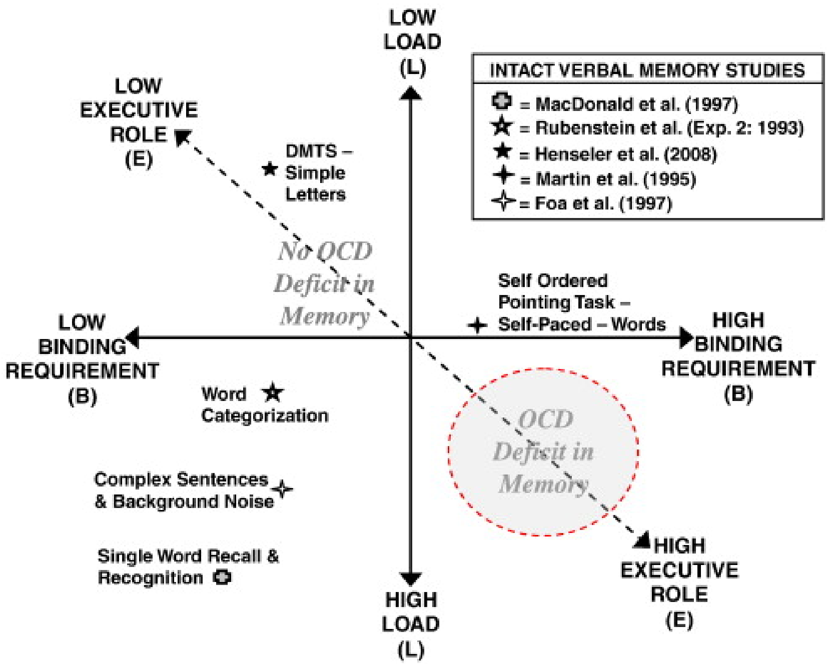
In a simple (encode: 4 letters and memory task: same/different single letter) delayed-match-to-sample task (DMTS), Henseler et al. (2008) failed to report any significant group differences as OCD patients (92.6%) performed at a similar ceiling level to controls (93.5%). This task called minimally upon the EBL factors: there were no distractors to suppress, the stimuli were non-threatening, and binding requirement was minimal as successful performance required the remembrance of 4 individual letters (within loop limits) not letter-to-location bindings. On a self-paced test (recall and recognition) of verbal WM, Martin, Wiggs, Altemus, Rubenstein, and Murphy (1995) presented participants with 16 words on a page, in a book of 16 pages. The only measure that revealed a significant group differences was total time taken, with OCD patients taking longer than controls to make 16 successive choices. As this task is predominantly visuospatial in nature (locate different words in spatial locations), we argue (based on the findings reported in Section 3) that this is an evidence of organizational impairments (i.e., ‘E’: executive functioning efficiency) slowing OCD patients' processing of each page. If this is the case, we predict that if individuals with OCD require longer to process a piece of information to their satisfaction relative to controls, interrupting this mid-flow will interfere with their ability to efficiently encode words, thus, highlighting that an executive impairment must be sufficiently operant to impair memory. As another example, Foa, Amir, Gershuny, Molnar, and Kozak (1997) reported that checkers' memory for contamination and neutral words was intact despite showing a concurrent perceptual distractibility (i.e., rated background noise as louder than controls). According to the EBL system we would not expect OCD memory impairments in this case as the disruption is not task-related and the task itself does not impose high EBL requirements.

In a classic study, often cited as evidence for lack of verbal deficits in OCD, MacDonald et al. (1997) investigated verbal recall and recognition. The experiment consisted of the following phases: (i) Study Phase 1, (ii) Distraction Phase 1, (iii) Recall Test, (iv) Study Phase 2, (v) Distraction Phase 2, and (vi) Recognition Memory Test. Specifically, (i) forty-eight words were presented, each for 1 s with 750 ms between each word, (ii) then a 7 minute distractor task was administered between the 48th word and the (iii) beginning of the free recall period. Then, after (iv) study phase 2 (identical in format to the first but with different words), there was a (v) 10 minute distractor task followed by a (vi) recognition task which presented single words requiring participants to indicate if they had (old judgment) or had not (new judgment) been presented in study phase 2 (iv). Considering this methodology in the EBL system presentation of a word for 1 second calls upon WM resources (i.e., executive-attention, phonological rehearsal) and LTM word representations (Cowan, 1999). Successful recall requires quick consolidation into verbal LTM, before presentation of the next word in 750 ms. An encoded word will experience primacy and recency interference from previous and subsequent words, respectively (Murdock, 1962), in addition to the substantial interference from the distractor tasks. This threatens veridicality of a word within early encoding, which likely impairs subsequent recall and recognition. In sum, this very difficult task obscures group differences by inducing a floor effect in all participants, an assertion supported by the very low recall proportion for checkers, non-checkers and controls of 0.179, 0.142, and 0.188, respectively. Furthermore, in a task of similar difficulty (Exp. 2; 50 words — 4 s each — from 5 categories), Rubenstein, Peynircioglu, Chambless, and Pigott (1993) failed to report any differences in memory of checkers (47%) compared to controls (49.6%). In these experiments, extant OCD/checkers' executive-memory impairments would need to be extremely acute to impact memory performance and significantly differentiate them from controls.

5.1.1.1. Summary: intact verbal memory in OCD

For the aforementioned studies, ceiling (e.g., Henseler et al., 2008) or floor effects (MacDonald et al., 1997; Exp. 2: Rubenstein et al., 1993) may underlie lack of verbal deficits. However, we are aware that the low group numbers of 11, 15, and 10 of Henseler et al., 2008, Foa et al., 1997 and MacDonald et al., 1997, respectively, may have resulted in these studies being underpowered. However, we see below that studies with similar group sizes (e.g., Simpson et al., 2006, Tallis et al., 1999, van der Wee et al., 2003 and van der Wee et al., 2007) reported significant group effects suggesting that OCD performance is better explained by scores on the EBL dimensions as opposed to group size (see Fig. 3).

Fig. 3. - Location of intact verbal memory studies within the *EBL* classification of OCD memory deficits.



5.1.2. Deficient verbal memory in OCD

Verbal memory impairment in OCD is invariably seen in studies that use words/sentences that benefit from organization according to implicit categories (see Table 3). Due to inefficiencies in their executive functioning, OCD patients fail to use mnemonic strategies (e.g., chunking according to categories) which reduces their memory performance relative to controls.

Table 3. - Studies reporting verbal memory deficits in OCD.

Authors	Method	Task requirements	Groups compared	Behavioral findings
Sher et al. (1984)	Logical method subtest of WMS	Listen to short story, recall and recognition requires semantic linking	Frequent vs. occasional vs. infrequent checkers vs. controls (MOCI)	Checkers deficit in recalling meaningfully linked sequences
Tuna et al. (2005)	Cued word recall and recognition	Memorize 48 word pairs presented for 3 s: 24 neutral-neutral and 24 neutral-threat	17 OCD patients (YBOCS: 22.3) vs. 16 subclinical checkers and 15 controls (MOCI)	OCD patients had poorer recall and recognition for all word pair types = general memory deficit
Irak and Flament (2009)	Focused, divided and passive attention	Attend to words (threat vs. neutral) in a range of conditions. Various recall and recognition tasks at end.	24 subclinical checkers (> 4 checking MOCI) vs. 22 controls (0–1)	Subclinical-checkers had attentional bias and better recall and recognition for threat stimuli compared to controls.
Rubenstein et al. (1993)	Cued word recognition	Memorize 60 word pairs presented for 5 s. Identify study words among 60 lures	20 subclinical checkers vs. 20 controls	Advantage for checkers
de Geus et al. (2007)	California Verbal Learning Task (CVLT)	Recall (short and long term), recognition, semantic clustering, attention.	39 Chronic therapy resistant OCD patients (YBOCS: 27.3) vs. 26 controls	OCD patients had poorer 1st trial recall and learned less words over 5 trials
Savage et al. (2000)	CVLT	Recall (short and long term), recognition, semantic clustering, attention.	33 OCD patients (YBOCS: 19.5) vs. 30 controls	OCD patients poorer recall, recognition, and semantic clustering
Deckersbach et al. (2004)	CVLT	Recall (short and long term), recognition, semantic clustering, attention.	30 OCD patients (YBOCS: 19.3) vs. 30 Bipolar Disorder vs. 30 controls	OCD patients were poorer organizing word lists. OCD's long-delayed free recall mediated by semantic clustering during encoding
Deckersbach et al. (2005)	CVLT	Recall (short and long term), recognition, semantic clustering, attention.	20 OCD patients (YBOCS: 22.5) vs. 20 Bipolar Disorder vs. 20 controls	Improved semantic clustering when directed to group words to category
Zielinski et al. (1991)	CVLT	Recall (short and long term), recognition, semantic clustering, attention.	OCD patients (DSM-III-R/MOCI) vs. controls	OCD patients poorer only on intrusions measure
Segalas et al. (2008)	Spain-Complutenase Verbal Learning Task (modified CVLT)	Recall (short and long term), recognition, semantic clustering, attention.	50 OCD patients (YBOCS: 20.2) vs. 50 controls	OCD patients poorer recall, recognition not moderated by org strategies
Cabrera et al. (2001)	Complex sentences	Content extraction and recognition	21 OCD patients (DSM-IV) vs. 21 controls	OCD patients poor semantic integration no difference in recognition
Sawamura et al. (2005)	Modified version of Iddon et al.'s (1998) verbal strategy task	Recall of 20 words presented for 1 min. Recognize these 20 words among 20 distractors. Semantic categorization.	16 OCD patients (YBOCS: 14.6) vs. 16 controls (MOCI-J)	OCD patients had poorer recall and recognition. Slower to semantically categorize words.

Sher, Mann, and Frost (1984) examined a range of verbal (and visuospatial) memory tests but only found verbal deficits for checkers in the Logical Memory subtest of the Wechsler Memory Scale (WMS; Wechsler & Stone, 1945). A short story is read to the participant with recall occurring immediately and then after 30 min. This is one of the earliest studies to highlight the importance of encoding impairments (i.e., in organizing meaningful episodic information) which we propose would occur in the EB (failure of E to reduce B and L) and so explain checker's poorer memory.

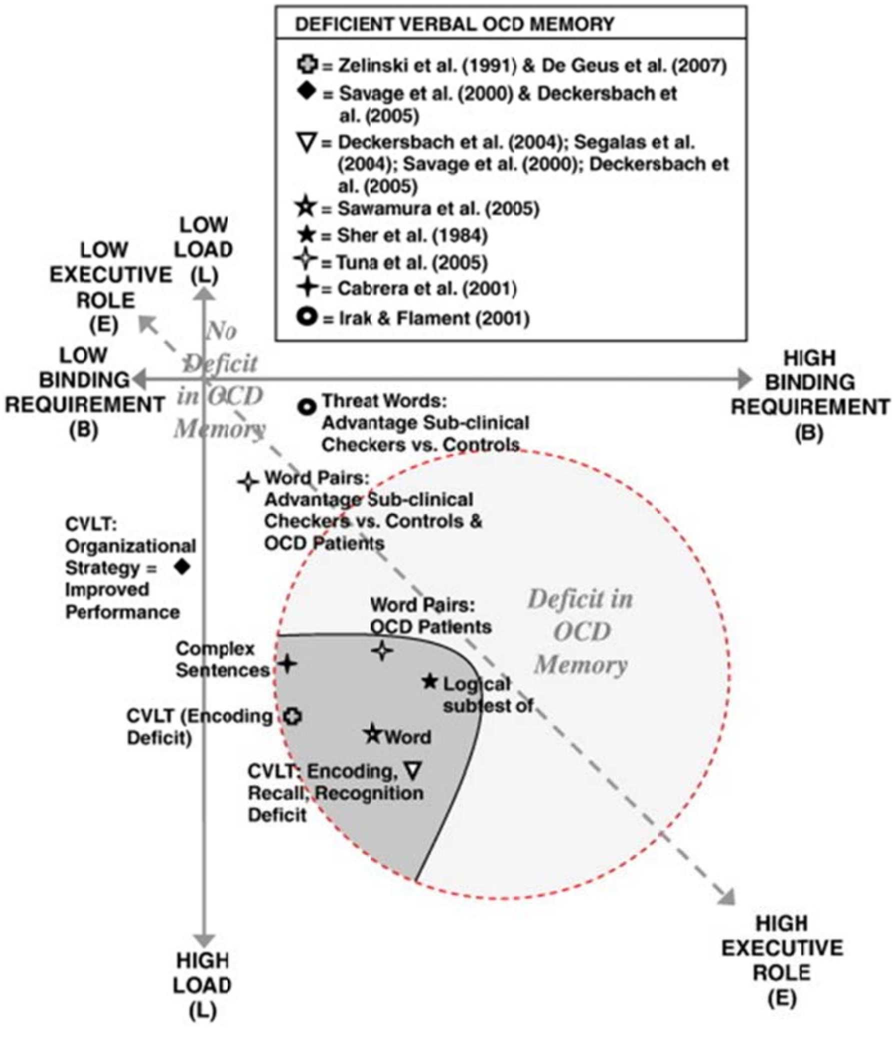
Tuna et al. (2005) tested recall and recognition for neutral–neutral word pairs (e.g., “shirt”–“book”) and neutral–threat word pairs (e.g., “music”–“fire”). OCD patients had poorer recall and recognition than subclinical checkers and controls for both neutral and threat-relevant stimuli, which was taken as evidence of a general mnestic deficit not influenced by memory task (recall vs. recognition) or emotional valence (neutral vs. contamination vs. threat). The performance advantage of subclinical checkers for threatening words over neutral was also observed in a study that used three attentional tasks (focused, divided, and passive) that measured recall and recognition memory (Irak & Flament, 2009). The stability of this effect was further substantiated by Rubenstein et al. (Exp. 3: 1993) who reported a similar advantage for checkers in word-pair recall and recognition. Revealingly, in the same study, checkers had impaired memory for actions (Exp. 1A; discussed below in deficient visuospatial memory Section 5.2.3.), leading the authors to conclude that differences in schematic organization may have differentiated their memory performance from controls. We argue that word-pair and action tasks likely stressed different cognitive resources: simple rehearsal within the phonological loop vs. visuospatial maintenance involving executive organization, complex binding, and high load. Therefore, in these experiments, checkers' perseveration/attentional biases may provide a memory advantage (vs. OCD patients; Tuna et al., 2005 or controls; Irak and Flament, 2009 and Rubenstein et al., 1993) for stimuli that have a low classification score across the EBL dimensions, i.e., over-rehearsal increases the strength of words maintained and subsequently retrieved from memory.

A frequent measure of verbal memory and learning in OCD is the California Verbal Learning Test (CVLT; Delis, Kramer, Kaplan, & Ober, 1988). The CVLT is usually administered in the following manner. First, 16 words are presented orally for 5 trials with free recall occurring after each trial. An interference list is presented after the 5th trial. Second, a test of short- and long-delayed (20/30 min) free recall is administered. Third, a delayed recognition test requiring participants to identify previously presented words among distractors. As a result the CVLT measures: (1) attention and WM (recall after first trial), (2) short and long term free recall, (3) semantic clustering (ability to categorize words over trials 1–5), and (4) recognition. de Geus, Denys, Sitskoorn, and Westenberg (2007) reported reduced trial-1 recall accuracy for therapy resistant OCD patients relative to controls, no differences were observed for trials 2 through 5 indicating intact verbal memory capacity. Trial 1 is more of a measure of attention (immediate span) than memory per se and as such, group differences are attributable to an inability to correctly attend to each word. The consistency of this impairment across studies (e.g., Deckersbach et al., 2004, Savage et al., 2000 and Segalas et al., 2008) indicates that poor initial attention is a stable deficit in OCD CVLT performance. Savage et al. (2000) reported that OCD patients: (1) memorized less information during encoding (trial 1), (2) used less efficient organizational strategies, and (3) had no deficit in capacity for verbal information over short and long delays. Indeed, when given category cues, OCD patients showed a disproportionate improvement in long-delayed recall where performance was now normal, a pattern also observed by Deckersbach et al. (2005). However, it is important to note that several CVLT studies (Deckersbach et al., 2004, Segalas et al., 2008 and Zielinski et al., 1991) and two using complex verbal material (Cabrera et al., 2001 and Sawamura et al., 2005) have reported similar, additional, and different performance profiles for OCD (see Table 2 for more details).

5.1.2.1. Summary: deficient verbal memory in OCD

Generally, OCD deficits in verbal memory occur when the task benefits from some form of input organization, which was evident in story recall (Sher et al., 1984), word list categorization (Sawamura et al., 2005), and CVLT performance (e.g., Savage et al., 2000). We saw that in the CVLT task impairment was influenced by the specific cognitive profile of each OCD group: Efficient or inefficient executive functioning (E) will increase or decrease memory load (L), respectively (see Fig. 2A), which influences the magnitude and type (e.g., trial-1 vs. semantic clustering) of memory impairment observed. OCD patients compared to sub-clinical checkers showed impaired and enhanced word-pair memory performance, respectively (Irak and Flament, 2009 and Tuna et al., 2005), which leads us to propose that executive functioning differs between these two groups. For example, sub-clinical checkers may over-rehearse (e.g., Tuna et al., 2005) and/or have attentional biases (e.g., Irak & Flament, 2009) which strengthen the representation of simple stimuli in memory (see Fig. 4). In addition, co-morbidities in patients (e.g. depression) might amplify their executive deficits compared to subclinical checkers (cf. Moritz et al., 2003 and Rampacher et al., 2010).

Fig. 4. - Positioning of deficient verbal memory studies within the EBL classification. The scale has been adjusted to allow clearer representation of verbal memory studies. Observe that verbal memory impairments cluster around inefficient executive functioning (E) and memory load (L) as proposed in the distinction we draw between verbal and visuospatial memory impairments in OCD (see Fig. 2A vs. 2B).



5.2. Visuospatial memory

Visuospatial memory impairments are most commonly observed in OCD, however, when visuospatial tasks are low on all EBL dimensions then no impairments in memory should occur. In addition, we expect studies that varied load to report intact and deficient OCD memory for lower and higher load levels, respectively, which we attribute to executive functioning failing to meet increasing task demands.

5.2.1. Intact visuospatial memory

Studies that score low on the EBL dimensions invariably report intact visuospatial memory as they are: (1) within visuospatial sketchpad capacity (i.e., low memory load), (2) low executive requirements (successful maintenance requires low attention and/or organization if undisturbed (e.g., Kessler & Kiefer, 2005)) and (3) low binding requirement (see Table 4).

Table 4. - Studies reporting intact non-verbal memory in OCD.

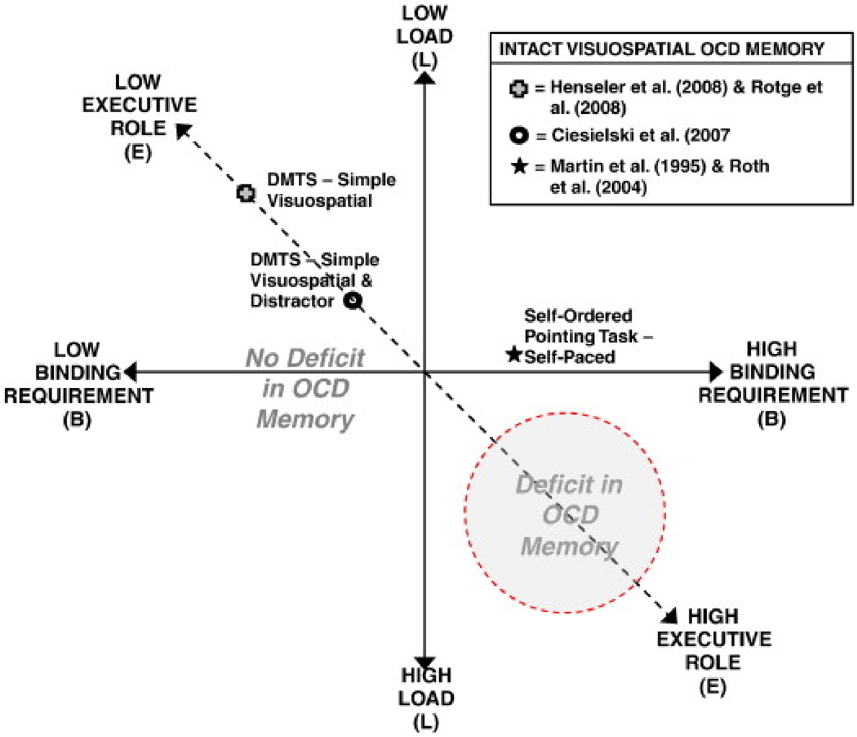
Authors	Method	Task requirements	Groups compared	Behavioral findings
Henseler et al. (2008)	Delayed match to sample (WM task)	Encode 5 × 5 matrix with 4 squares filled. Indicate if a probe is correctly located	11 OCD patients (YBOCS: 21.0) vs. 11 controls	No differences
Ciesielski et al. (2007)	Delayed match to sample (WM task)	Encode 3 × 3 matrix with 2 squares filled. Choose correct probe from 2 choices	8 OCD patients (YBOCS: 25.6) vs. 8 controls	No difference for simple DMTS or distractor DMTS
Roth et al. (2004)	Self-ordered pointing task	Self-paced abstract selection task	30 OCD patients (YBOCS: 28.1) vs. 24 controls	No differences
Martin et al. (1995)	Self-paced selection of drawings of animals and nonsense objects	Always select a different animal/object/word	18 OCD patients (DCM-III-R) vs. 18 controls	No differences

Two simple delayed-match-to-sample (DMTS) tasks failed to report any difference in OCD memory performance relative to controls (Ciesielski et al., 2007 and Henseler et al., 2008) due to low scores on all EBL dimensions. Roth, Milovan, Baribeau, O'Connor, and Todorov (2004) mainly used the Self-Ordered Pointing Task (SOPT; Petrides & Milner, 1982) as a measure for executive WM requiring the ability to generate and monitor a sequence of responses. On each page of a booklet with 12 pages several abstract designs were presented. On page 1, participants were asked to select a design by pointing at it, then to turn to page 2 and point to a different design until they completed the full 12 page booklet. Participants were instructed not to choose the same design more than once and not to choose designs in the same spatial location on two consecutive pages (designs and locations were randomized across pages). There were no differences between OCD patients and controls in terms of errors, time taken, likelihood of using an organizational strategy, and specific organizational strategy used. One potential explanation for these null findings is the observation that on average all participants took approximately 20 s per page which may have been sufficient to allow OCD patients to compensate for extant executive dysfunction (see also Martin et al., 1995).

5.2.1.1. Summary of intact visuospatial memory

Low load tasks (e.g., Ciesielski et al., 2007, Henseler et al., 2008 and Rotge et al., 2008) with minimal executive, binding and load requirements are unlikely to produce OCD memory deficits. In addition, self-pacing appears to prevent performance deficits in OCD patients (e.g., Martin et al., 1995 and Roth et al., 2004) by allowing individuals to attain higher threshold of certainty or to satisfy their obsessions and/or compulsions to some degree (see Fig. 5). Following this logic, limiting decision-making time curtails some or all of these strategies which may put OCD patients' central executive sufficiently under pressure to impair their memory.

Fig. 5. - Positioning of intact verbal memory studies within the EBL classification.



5.2.2. Intact and deficient visuospatial memory within the same study

The following are examples of intact and deficient visuospatial memory within the same study (see Table 5) they highlight the delicate manner in which executive-functioning, binding complexity and load interact to negate or produce visuospatial memory deficits.

Table 5. - Studies reporting intact and deficient non-verbal memory in OCD. Please observe that we include a study by Morein-Zamir et al. (2010) * in this section which failed to show OCD spatial memory impairment in the SWM task (i.e., as used by Purcell et al., 1998a and Purcell et al., 1998b, as they did report memory impairment in another spatial task (Paired Association Learning).

Authors	Method	Task requirements	Groups compared	Behavioral findings
van der Wee et al. (2003)	*n*-back (0,1,2,3 load levels)	Continual monitoring and updating of information in WM	11 OCD patients (YBOCS: 25.8) vs. 11 matched controls	No diff at 0, 1, 2 *n*-back. Diff for 3 *n*-back task
van der Wee et al. (2007)	*n*-back (0,1,2,3 load levels). Before and after pharmacological intervention	Continual monitoring and updating of information in WM	14 Psychotropic free OCD patients. 7 responders (YBOCS: 24.4) vs. 7 non-responders (24.7)	Improvement at 3-back level only for responders
Purcell et al. (1998a)	Spatial WM	Spatial search task in spatial locations.	23 OCD patients (YBOCS: 22.4) vs. 23 matched controls	No diff for 2, 3, 4 (low difficulty) Diff for 6 and 8 (high difficulty)
Purcell et al. (1998b)	Spatial WM	Spatial search task in spatial locations.	30 OCD patients (YBOCS: 24.1) vs. 30 matched controls	No diff for 2, 3, 4 (low difficulty) Diff for 6 and 8 (high difficulty)
Morein-Zamir et al. (2010)*	Spatial WM	Spatial search task in spatial locations.	18 OCD patients (DSM-IV-TR) vs. 18 matched controls	No diff on between-search errors or strategy scores
Morein-Zamir et al. (2010)*	Paired Association learning	Learning associations between geometric patterns and spatial locations	18 OCD patients (DSM-IV-TR) vs. 18 matched controls	No diff level 3 (low difficulty) Diff for 6 and 8 (high difficulty)
Zielinski et al. (1991)	Corsi Block-Tapping Test	Spatial span and number of correct repeated sequences	OCD patients (DSM-III-R/MOCI) vs. controls	OCD patients poorer span and correct sequences
Zitterl et al. (2001)	Intermediate (Lern- und Gedachtnistest; LGT-3) and immediate (Corsi Block-Tapping Test)	Spatial span and number of correct repeated sequences	27 non-depressed OCD patients (YBOCS: > 16) vs. 27 controls	OCD patients poorer on intermediate and immediate measures
Moritz et al. (2003)	Corsi Block-Tapping Test	Spatial span and number of correct repeated sequences	32 OCD patients (YBOCS: 23.52) vs. 20 controls.	OCD patients poorer at corsi block tapping
Boldrini et al. (2005)	Corsi Block-Tapping Test	Span and supraspan	25 OCD patients (YBOCS: 22.7) vs. 15 panic vs. 15 controls	OCD patients impaired on span and supra span

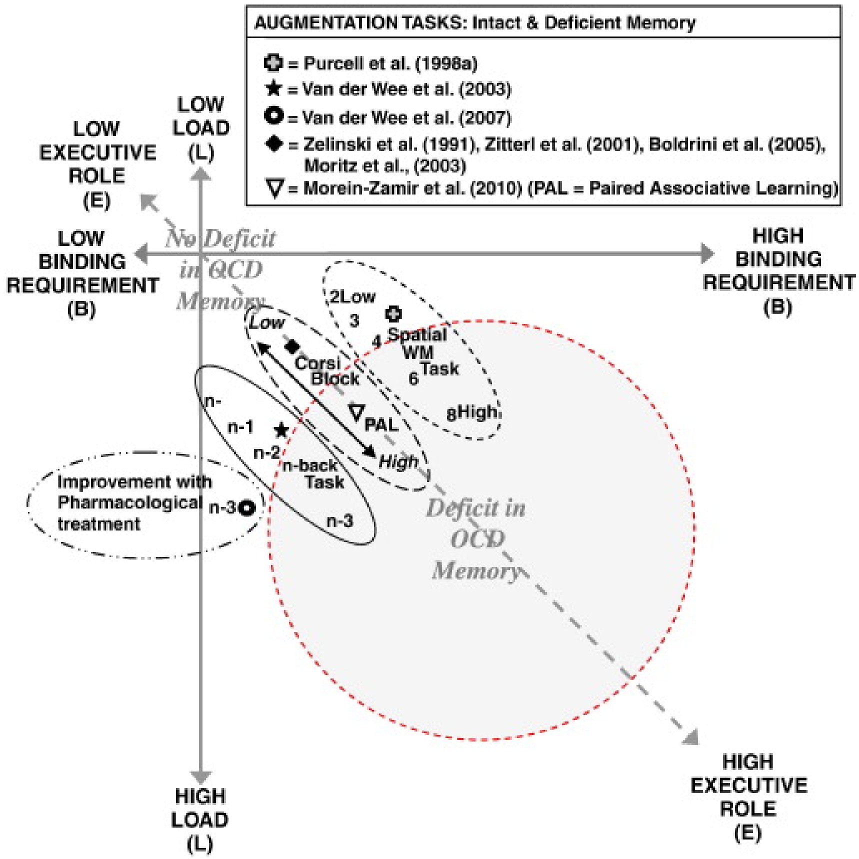
van der Wee et al. (2003) used a spatial variant of the n-back WM task with four levels of load. OCD individuals and controls had equivalent performance for 0-, 1- , and 2-back indicating that OCD spatial WM capacity was intact. It was only at the 3-back load level that patients with OCD significantly differed from controls with errors of 48% vs. 25%, respectively. Further, van der Wee et al. (2007) reported that OCD patients which responded favorably to pharmacological treatment showed improvement only in their 3-back performance. Thus, poor OCD 3-back performance is attributable to dysfunctional executive control (E) failing to provide efficient strategies in the face of attention-dependent multimodal bindings (B) and increased memory load (L) (see Fig. 2B), with improvements in memory likely attributable to improvements in executive functioning at the level of organization and/or suppression.

Stability of OCD impairment at higher load levels is supported across a range of tasks. For example, the Paired Association Learning task (PAL; Sahakian et al., 1988) which required the binding and maintenance of shapes to spatial locations in memory across increasing levels of load and so scored highly in the EBL classification system. Morein-Zamir et al. (2010) attributed the impairment of the OCD group (at more demanding load levels 6 and 8) to a dysfunction in nonspatial associative learning. However, they did report intact performance in a test of spatial WM (SWM) at low and high load levels, which was interesting as another group reported impaired OCD performance at higher load levels (see Purcell et al., 1998a and Purcell et al., 1998b). Purcell and colleagues observed that OCD patients were more likely to return to a previously searched box at higher load levels (i.e., 6 and 8 boxes), which was indicative of impairment in adopting a systematic search strategy (E: organization) and inability to correctly manipulate internal WM representations. Critically we suggest that absence (Morein-Zamir et al., 2010) and presence (Purcell et al., 1998a and Purcell et al., 1998b) of OCD memory impairment in this SWM task suggest that the specificity of executive dysfunction (E) between OCD-groups may differ between studies. Further evidence for OCD memory impairment at higher (not lower) load levels is supported by their performance on the Corsi block-tapping test (see Table 5: Boldrini et al., 2005, Moritz et al., 2003, Zielinski et al., 1991 and Zitterl et al., 2001).

5.2.2.1. Summary of intact and deficient visuospatial memory within the same study

In all these tasks (n-back, SWM, PAL, Corsi-block) we saw that increasing load in the SWM domain differentiates OCD patients from controls; it is only when executive functioning is stressed at high loads that the contents of memory become unmanageable, i.e., inefficient executive functioning (E) fails to reduce memory load (L) (see Fig. 6). van der Wee et al. (2007) proposed that OCD performance on the n-back was state dependent, as treatment responders showed significantly less errors in 3-back performance compared to non-responders.

Fig. 6. - Positioning of intact and deficient visuospatial memory studies within the EBL classification.



5.2.3. Deficient visuospatial memory

Studies that show deficits in visuospatial memory invariably share the following characteristics: (1) they exceed visuospatial sketchpad capacity (> 6 items), (2) have high executive requirements, and (3) are high in binding complexity (see Table 6). In essence these are the same characteristics as for the high load conditions in the studies reviewed in the previous section (see Fig. 6).

Authors	Method	Task requirements	Groups compared	Behavioral findings
OCD memory impairments in single methodologies				
Rubenstein et al. (1993)	Write, observe, or perform 90 actions	After completing 90 actions write down all actions they could remember	20 subclinical checkers (MOCI-checking: unknown) vs. 20 controls (MOCI-checking: ≤ 2)	Checkers remembered fewer actions and greater errors vs. controls.
Purcell et al. (1998a)	DMTS	Maintain complex visuospatial stimulus and select it from 3 close alternatives	23 OCD patients (YBOCS: 22.39) vs. 23 matched controls	OCD patients poorer DMTS selection vs. controls.
Tallis et al. (1999)	Recurring Figures Task	Maintain previously copied abstract figure and recall immediately and after 30 min	12 OCD patients (primarily checkers: Pauda: 72.6) vs. 12 matched controls	OCD patients poorer than controls on RFT.
Zielinski et al. (1991)	Recurring Figures Task	Maintain previously copied abstract figure and recall immediately and after 30 min	OCD patients (DSM-III-R/MOCI) vs. controls	OCD patients impaired on immediate and delayed components of RFT.
Simpson et al. (2006)	Benton Visuospatial Retention Test	View abstract design then recall from memory	15 comorbid OCD (YBOCS: 26) vs. current OCD (19.5) vs. history-of-OCD (9.8) vs. Controls (0.34)	OCD patients less correct responses.
OCD RCFT performance impairment studies				
Martinot et al. (1990)	Rey Complex Figure Task (RCFT)	Overall memory score and completion time	16 Nondepressed OCD patients (MOCI: 16.9) vs. 8 controls	OCD patients impaired in memory score and slower.
Savage et al. (1999)	RCFT	Copying of abstract figure, immediate, delayed recall, recognition, and organization	20 OCD patients (YBOCS: 20.9) vs. 20 Controls (0.4)	OCD patients impaired immediate and delayed recall. Immediate recall mediated by org strat during copy.

Savage et al. (2000)	RCFT	Copying of abstract figure, immediate, delayed recall, recognition, and organization	33 OCD patients (YBOCS: 19.5) vs. 30 Controls	OCD patients impaired immediate recall, copy to immediate recall and copy organization.
Deckersbach et al. (2000)	RCFT (reliability and validity of scoring)	Copying of abstract figure, immediate, delayed recall, recognition, and organization	71 OCD patients (YBOCS: 21.2) vs. 55 Controls	OCD patients impaired in organization, copy accuracy, copy organization.
Segalas et al. (2008)	RCFT	Copying of abstract figure, immediate, delayed recall, recognition, and organization	50 OCD patients (YBOCS: 20.2) vs. 50 Controls	OCD patients impaired on immediate, delayed recall and recognition.
Boldrini et al. (2005)	RCFT	Copying of abstract figure and recall	25 OCD patients (YBOCS: 22.7) vs. 15 Panic vs. 15 Controls	OCD patients impaired on copy and overall recall.
Penades et al. (2005)	RCFT	Copying of abstract figure, immediate, delayed recall, recognition, and organization	35 OCD patients (YBOCS: 29.3) vs. 33 Controls	OCD patients impaired immediate recall and copy organization.
Shin et al. (2004)	RCFT	Qualitative analysis of copy, immediate, delayed, recognition and organization	30 OCD patients (MOCI: 14.5) vs. 30 Controls (3.5)	OCD patients impaired immediate recall and copy organization. Qualitative analysis: copy = poorer planning and fragmentation.
Rampacher et al. (2010)	RCFT	Copying of abstract figure, delayed recall, and organization	40 OCD patients (YBOCS: 20.9; BDI: 15) vs. 20 major depressives (YBOCS: 0; BDI: 16.3) vs. 40 controls	OCD patients impaired on copy but not organization compared to MDD patients. Only OCD severity correlated with visuospatial organization.
Jang et al. (2010)	RCFT	Copying of abstract figure, delayed recall, and organization	144 OCD patients (YBOCS: 23.1; BDI 17.95; BAI: 19.67) vs. 144 Controls	OCD patients impaired in recall and organization which correlated with obsession/checking and symmetry/ordering dimensions.

Split OCD group by age of onset or primary symptom				
Hwang et al. (2007)	RCFT	Copying of abstract figure, immediate, delayed recall, recognition, and organization	24 early-onset (≤ 17 years: YBOCS: 22.2) OCD vs. 24 late-onset (≥ 21: YBOCS: 23.4) vs. 24 controls	Late-onset impaired on immediate and delayed recall.
Roth et al. (2005)	RCFT	Copying of abstract figure, immediate, delayed recall, recognition, and organization	21 early-onset (≤ 12 years: YBOCS: 23.4) OCD vs. 13 late-onset (≥ 24.8: YBOCS: 23.4) vs. 24 controls	Late-onset impaired on delayed recall.
Cha et al. (2008)	RCFT	Copying of abstract figure, immediate, delayed recall, recognition, and organization	24 checking-OCD (25.4) vs. 23 cleaning-OCD (24.7) vs. 20 controls	Checkers significantly impaired in immediate and delayed recall vs. cleaners and controls. No difference in copy accuracy.
No OCD RCFT impairments found				
Simpson et al. (2006)	RCFT	Copying of abstract figure, immediate, delayed recall, recognition, and organization	15 Comorbid OCD (YBOCS: 26) vs. Current OCD (19.5) vs. History-of-OCD (9.8) vs. Controls (0.34)	OCD patients did not differ from controls on any RCFT measure.
Bohne et al. (2005)	RCFT	Copying of abstract figure, immediate, delayed recall, recognition, and organization	21 OCD patients (YBOCS: 16.9) vs. 23 trichotillomania vs. 26 controls	OCD and TTM did not differ from controls.
Moritz et al. (2003)	RCFT	Copying of abstract figure, immediate, delayed recall, recognition, and organization — controlling for depression	32 OCD patients (YBOCS: 23.52) vs. 20 controls.	OCD patients did not differ from controls on any RCFT measure.

Recovered OCD patients — RCFT impairments remain				
Rao et al. (2008)	RCFT	Copying of abstract figure, immediate, delayed recall, recognition, and organization	30 Recovered OCD patients (YBOCS: 2.57) vs. 30 controls (2)	Recovered OCD patients remained impaired on immediate and delayed recall.
OCD RCFT therapy studies				
Kim et al. (2002)	RCFT — pharmacological intervention	Baseline vs. 4 month comparison. Pharmacological intervention.	39 OCD patients (YBOCS at baseline: 25.4) vs. 31 Controls (0.2)	OCD patients immediate and delayed impairments still after 4 months.
Roh et al. (2005)	RCFT — pharmacological intervention	Baseline vs. 4 month vs. 1 year follow up. Pharmacological intervention.	21 OCD patients (YBOCS at baseline: 26.9) vs. 20 controls	OCD patients immediate and delayed impairments still after 1 year.
Kuelz et al. (2006)	RCFT — cognitive behavioral therapy	Baseline vs. 3 month follow-up. Cognitive –behavioral treatment	30 OCD patients (YBOCS at baseline: 24.2) vs. 39 Controls (0.5)	OCD patients immediate and delayed improvements, specific to major responders.
Buhlmann et al. (2006)	RCFT — cognitive training	Organization training vs. no training	35 OCD patients (YBOCS at baseline: 20.1) vs. 36 Controls	Training improved organization during encoding. Immediate and delayed recall still impaired.
Park et al. (2006)	RCFT — cognitive training	Before vs. After: Cognitive Training for 5 weeks	Baseline: 15 Treatment OCD patients (YBOCS:21.1) vs. 15 No-treatment OCD (18.7)	Treatment group improved: copy, immediate, delayed, organization and symptoms.

Rubenstein et al. (Exp. 1a: 1993) examined sub-clinical checkers' ability to recall if they had written, observed, or performed an action they had heard. They had unlimited time to complete the memory tasks. Subclinical checkers remembered fewer actions (56.2 vs. 66.1), were more likely to confuse whether they had written, observed or performed a given action (1.2 vs. 0.4) and made more errors of commission compared to controls (0.5 vs. 0.1). This shows that checkers are poorer at recalling their own actions in general and deficient in recalling details of their actions specifically. No group differences in a control condition (memory for cartoons) suggests that impairments are a property of actions not memory capacity per se. Remembering actions in their situational context taps into the episodic buffer deficits in terms of attention-demanding multimodal bindings described in Section 3.

In a DMTS task, Purcell et al. (1998b) presented a complex target stimulus (rectangle with different internal arrangements of color and shape) for 4 s. The participant then had to select the correct target from three distractors. OCD patients were significantly less accurate than controls (85.11% vs. 90.43%), which is interesting as the DMTS tasks of Henseler et al. (2008) and Ciesielski et al. (2007) failed to report group differences. Overall, accuracy was high for all three studies suggesting low overall load (all > 85%). However there are two features of the particular methodology employed by Purcell et al. (1998b) that may explain the memory impairment in OCD patients. First, binding requirements were much higher as an arbitrary shape, color and location had to be integrated requiring more executive control during encoding and maintenance than the other two studies. Second, the employed recall probe was more complex with 4 options being presented and where two of these were partially correct (in shape or color). Thus, the 4 options at recall may have been particularly distracting for OCD patients' already challenged executive control, hence, interfering with correct retrieval. Taken together, executive control was much more challenged during encoding, maintenance and retrieval in the Purcell et al. task, leading to the observed group differences.

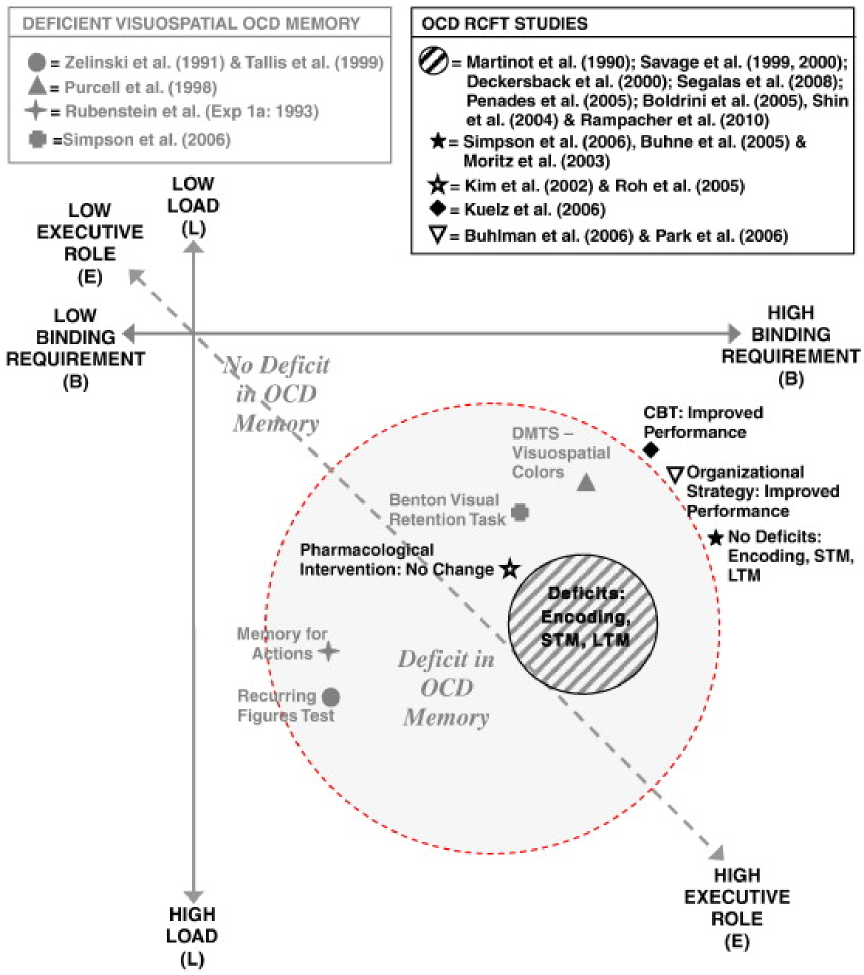
5.2.3.1. Figures Recall, Recurring Figures Task and Benton Visual Retention Task

Tallis et al. (1999) reported impaired performance of OCD (primary symptom was checking) patients on two tests of visuospatial memory. First, in the Figures Recall task (Coughlan & Hollows, 1985), where the participant has to copy an abstract line drawing and then recall it immediately and after a delay. Second, in the Recurring Figures Task (RFT; Kimura, 1963), where 20 geometric or irregular nonsense figures are presented for 3 s each. After this the participant must identify those 20 cards from 140 in total by classifying each card as ‘old’ or ‘new.’ In this latter task performance for OCD patients was poorer overall and they were more likely to identify new stimuli as old (i.e., false positives; see also Zielinski et al., 1991). Increasing symptom severity was associated with poorer overall score and more false positives. In the task similar to the RFT, Simpson et al. (2006) reported attenuated OCD performance on the Benton Visual Retention Task (BVRT; Benton, 1974). We suggest that executive impairments of organization as observed in the Figural Fluency (e.g., Fenger, Gade, Adams, Hansen, Bolwig, & Knudsen, 2005) and Trail Making Tasks (Kim et al., 2002, Penades et al., 2005 and Roh et al., 2005) (see Table 1) explain OCD RFT and BVRT performance: poor executive organization (E) during encoding reduces the veridicality of memory traces that are maintained in WM and passed into LTM which in turn play a role in symptom severity.

5.2.3.2. Summary of deficient visuospatial memory

All the aforementioned tasks require extensive executive control within the visuospatial domain which manifested itself in a number of OCD memory impairments. First, checkers were poorer at remembering actions, which by their nature are episodically rich requiring the integration of information from a number of domains, such as, temporal order and spatial location of actions (e.g., Rubenstein et al., Exp 1a: 1993). Second, Purcell and colleagues highlighted that OCD patients were poorer at remembering abstract shapes, their colors and their locations, a task requiring focused attention of (1) shape–color–location bindings and (2) suppression of distractors that shared features with the target during recall. Third, OCD performance on the FR and RF tasks (Tallis et al., 1999 and Zielinski et al., 1991) and BVR (Simpson et al., 2006) tasks indicates that OCD patients have consistent executive deficits which impair their ability to efficiently attend, organize, and actively retain visuospatial information (see Fig. 7 and Table 1: Executive Impairments).

Fig. 7. - Positioning of deficient visuospatial (light gray text) RCFT (black text) studies within the EBL classification. The scale has been adjusted to allow clearer representation of visuospatial memory studies. To minimize cluttering we have used a shaded area to indicate the dimensional location of the RCFT studies that reported OCD impairments at the level of encoding and/or recall and/or recognition.



5.2.3.3. Rey Complex Figure Task

The most common measure of visuospatial memory performance in OCD is the Rey Complex Figure Test (RCFT: Osterrieth, 1944). First, participants are presented with the Rey Complex Figure (RCF) that they draw immediately without distraction revealing their ability to copy/encode. Then, distractor tasks are completed and after 3 min they recall the RCF, which provides a measure of immediate recall. Next, more distractor tasks are completed and after 30 min they again re-draw the RCF as a measure of delayed recall. Finally, twenty-four figures are presented and the participant has to identify twelve that belong to the RCF from twelve that do not, serving as a measure of recognition (Segalas et al., 2008). Chiulli, Haaland, Larue, and Garry (1995) highlighted the functional distinctions of the RCFT: (1) Copy: perceptual, visuospatial, and organizational, (2) Immediate recall: amount and quality of information encoding, and (3) Delayed recall: amount and quality of information stored and retrieved from episodic memory.

Savage, Baer, Keuthen, Brown, Rauch, and Jenike (1999) (and Deckersbach et al., 2000, Penades et al., 2005, Savage et al., 2000 and Segalas et al., 2008; see also Martinot et al., 1990) reported intact copy but impaired immediate and delayed performance in OCD patients. Preserved copy performance and no additional loss of information between the immediate and delayed conditions indicated that memory capacity (see also Penades et al., 2005 who reported intact memory for faces) did not moderate memory performance. Rather, Savage et al., 1999, Savage et al., 2000 and Penades et al., 2005 suggested that poor use of organizational strategies during the copy condition mediated performance in the immediate recall condition. A point supported by Savage et al. (1999) who observed that OCD patients are more likely to attend to details and less likely to shift their attention to larger RCFT components compared to controls (see also Shin, Park, Kim, Lee, Ha, & Kwon, 2004). Furthermore, Penades et al. (2005) highlighted that obsessional severity was associated with greater impairments in organizational strategies and immediate recall. This suggests that unnecessary attention to detail (E: organization, set-shifting) interferes with early encoding (i.e., fragmentation in EB) which impairs memory (B and L) and possibly plays a role in obsessional symptoms.

5.2.3.4. No group differences in RCFT performance

Simpson et al. (2006) proposed that depression and/or between study ratio differences in executive dysfunction may explain a failure to report OCD RCFT memory impairments. Both of these fit the current EBL explanation in that performance differences between studies are attributable to the respective executive deficits of the OCD group tested: (1) Depression: Moritz et al. (2003) reported that OCD patients with a higher comorbid depression forgot more RCFT information between copying and delayed recall compared to those with lower depression scores. They concluded that memory dysfunctions in OCD are moderated by comorbid depression a finding also supported by Segalas et al. (2008). However, Rampacher et al. (2010) proposed that organizational impairments were specific to OCD and not to major depressive disorders but did concede that depression may aggravate existing deficits in OCD. (2) Sub-group Ratios: Cha et al. (2008) found that a predominantly checking OCD subgroup had poorer immediate and delayed recall compared to cleaners and controls (also observed by Jang et al., 2010), which conforms to our notion of checking compulsions as the primary source of executive deficits (see 1, 2 and 3). In sum, a specific type of executive dysfunction is required to observe a memory impairment, one that is predominant in one OCD sub-group (checkers) but generally absent in another (cleaners), which may be aggravated by comorbid depression, and possibly influenced by age of onset (Hwang et al., 2007 and Roth et al., 2005).

5.2.3.5. RCFT and pharmacological and psychological interventions

Kim et al. (2002) examined OCD patients on the RCFT (among other tests) before and after a 4-month period of pharmacological treatment. At baseline OCD patients had similar copy — but impaired immediate and delayed recall compared to controls. Despite a significant improvement of immediate recall from baseline to follow-up, they remained significantly impaired compared to controls (see also Rao et al., 2008 and Roh et al., 2005). These studies indicate that certain executive and non-verbal deficits are stable and possibly candidate endophenotype markers for OCD (see Bannon et al., 2006, Chamberlain et al., 2005 and Rao et al., 2008) resisting pharmacological treatment. Psychological interventions which either implicitly (i.e., cognitive–behavior therapy; Kuelz et al., 2006) or explicitly (i.e., cognitive retraining; Buhlmann et al., 2006 and Park et al., 2006) targeted organizational strategies have been associated with improvements on RCFT memory performance and obsessional severity in OCD (i.e., Park et al., 2006). This highlights that not only is executive efficiency (E) malleable to intervention by improving how patients encode (integrated B = low L) information in memory (see Fig. 2B) (see also Buhlmann et al., 2006) but it can also attenuate symptom severity.

5.2.3.6. Summary of RCFT OCD performance

The RCFT is a task with the following EBL requirements that make OCD deficits very likely: (1) Executive-Functioning: For the RCFT, OCD patients show consistent executive impairments (E) in: (1) organization during early encoding, (2) attention to details over the whole and (3) shifting cognitive set from details to the whole. A failure to reveal OCD impairments on the RCFT is likely due to the tested OCD group not having a sufficient number of executive impaired patients, e.g., more cleaners than checkers (see Cha et al., 2008). (2) Binding Complexity: successful memory of multiple geometric shapes relies on binding. This occurs at the level of within-object binding (i.e., sides of triangle in bottom left corner) and between-object binding, where veridicality depends on the correct binding of parts in space relative to other parts (i.e., position of circle with 3 dots within triangle). Thus, poor executive functioning interferes with the veridicality of multiple

RCF bindings (B) in encoding, WM maintenance and LTM. (3) Load: load in the RCFT depends on the executive efficiency and binding complexity, in other words, the ability to chunk the complex figure into manageable sub-parts. For OCD patients, executive impairments (E) increase the load (L) and the binding complexity (B) of the RCF in memory (see Fig. 2B).

6. Comparison of EBL classification system to other models in the OCD literature

The EBL classification system allowed us to explain, in a unified manner, how executive impairments observed in OCD/checking tend to impair memory when the episodic buffer is extensively relied upon. However, we are aware that our EBL classification system is primarily cognitive in nature, which poses the question: How does it relate to alternative and more phenomenogical explanations of OCD symptoms in general and of memory impairments in particular?

Salkovskis (1999) provided one of the most influential models of OCD suggesting an integrated relationship between a number of variables. In the most general sense, this model saw early experiences and critical incidents as primers for the development of faulty assumptions and general beliefs. In turn, this motivates intrusive thoughts, images, urges and doubt which induce a misinterpretation of the personal significance of these intrusions. This misinterpretation is then maintained by an array of factors such as attention and reasoning biases, mood changes, counterproductive safety strategies, and neutralizing actions. These then feed back into the maintenance and shaping of existent and future intrusive thoughts. Within this phenomenological model of OCD the cognitive EBL factors we propose fall into the category of ‘attention and reasoning biases’, while our account exactly specifies the executive mechanisms that have distractibility/biases as origin and memory impairment as effect. Compared to Salkovskis' model, we argue for a more direct relationship between executive-memory impairments (as understood in the EBL system) and the content of obsessional thinking. The findings that executive functioning (i.e., ‘E’: organization) was associated with memory performance (for visuospatial stimuli high in ‘B’, see: Penades et al., 2005; and ‘L’, see: van der Wee et al., 2007) and severity of symptoms in OCD supports this assertion (see Park et al., 2006 and Tallis et al., 1999). We suggest that ‘critical incidents/early experiences/personal dispositions likely prime executive/attentional impairments to become operant when faced with an internal and/or external stimulus/intrusion associated with the original incident.

The role of inflated personal responsibility (i.e., preventing harms to others) has been identified as important in models of checking and impaired memory (Rachman, 2002 and Rachman et al., 1995). In the simplest interpretation, Rachman (2002) proposed that responsibility influences perceptions of harm, increasing anxiety and neutralizing checking attempts. However, checking only serves to increase responsibility and impair memory, which leads checkers to believe that their behaviors are out of control. A likely consequence would be increased attention to aspects of a memory representation which are deemed relevant or possibly neutralizing to the perceived responsibility/threat. However, as we saw in our work (Exp. 1 of Harkin et al., 2011) and others' (e.g., Savage et al., 1999), this could result in a narrow focus on specific stimulus details or deficient suppression of distracting thoughts/stimuli, which in any case comes at a cost for memory accuracy.

van den Hout and Kindt (2003) validated their OCD-memory model using the remember/know distinction. They showed that repetitively checking the same stimulus resulted in a shift in the nature of their memory recollections from being detailed and vivid (‘remember’ judgment) to being hazy, indefinite and unclear (‘know’ judgment). While the authors reported the outcome of checking, the exact mechanism of memory changes was not stated. A more specific indication of the mechanism underlying checking-related memory impairment was revealed by Radomsky and Alcolado (2010). They asked participants to mentally check (“…imagine your hand manipulating the knobs”; p.347) and then recall “Which three knobs did you check on the last trial?” (p.347). Those who engaged in mental checking were significantly less accurate than those who did not mentally check. The unnecessary mental manipulation and increased complexity (i.e., imagining your hand when it is not needed) caused by mental checking (E) likely interferes with the veridicality of knob-to-stove bindings (high in ‘B’) maintained in the episodic buffer.

More specifically, Ferreri, Lapp, and Peretti (2011) proposed that cognitive dysfunction in OCD (and in anxiety disorders in general) could be classified into four domains: (1) executive functioning (primarily attention), (2) memory (WM, episodic, autobiographical), (3) maladaptive cognitions (thoughts and beliefs), and (4) metacognitions (thoughts and beliefs about thoughts and beliefs). We suggest that our EBL system helps integrate the first two domains: primary executive dysfunction results in secondary memory impairment. In turn, we have previously proposed (Harkin & Kessler, 2009) that self-awareness (metacognition) of repeated loss of accuracy may decrease confidence in memory and increase the likelihood and strength of misleading intrusive thoughts (maladaptive cognitions) which would then be harder to ignore. This was supported by a recent study (Harkin et al., 2011), where we found a metacognitive deficit specific to high checkers (i.e., a dissociation between accuracy and confidence in a baseline condition). Thus, we argue that our EBL system not only complements the models of Salkovskis, 1999, Rachman, 2002, Rachman et al., 1995 and van den Hout and Kindt, 2003 and the classification proposed by Ferreri et al. (2011) but also provides a more specific and stringent cognitive framework for explaining and predicting executive-memory impairments in OCD.

7. Limitations of the EBL classification system

We highlight the following limitations to the EBL classification system. First, it is a good fit for OCD patients with prominent checking cognitions/behaviors, but appears not to describe symptoms such as cleaning or hoarding. We propose that if the EBL factors are sufficiently stressed (as discussed above) then memory impairment could be observed in symptoms other than checking. However, we do concur that due to the specific impairments (i.e., inhibition; Omori et al., 2007) and cognitive habits (i.e., iteratively checking the contents of memory, perseveration) associated with checking, this symptom is the most likely to affect executive functions that lie at the core of the EBL system.

Second, we do not make many solid conclusions regarding the relationship between the EBL and confidence in memory. Whereby, poor confidence may be a general factor – tightly linked to anxiety – which increases the likelihood that executive dysfunction will impair memory for tasks which load high on B and/or L dimensions. Alternatively or in addition, executive-memory impairment may result in poorer memory confidence which then motivates detrimental checking and/or obsessional thinking.

Third, we make no comment on the reviewed studies with respect to general cognitive abilities like intelligence. However, we agree with the extensive OCD literature review of Kuelz et al. (2004) – which covered many of the papers we examined – who stated that: “It is well established today that general intelligence is not affected in OCD” (p. 223). Finally, these limitations highlight the necessity for future experimental research to see if the EBL system does accurately predict where memory impairment will and will not occur.

8. Conclusions

This review reconciles inconsistent findings as to memory deficits in OCD by suggesting that the classic view in terms of modality-specific (verbal vs. visuospatial) deficits and/or general capacity issues might not be the optimal way of conceiving of the problem, while we propose to follow and extend the more recent argument that OCD memory impairments are secondary to executive dysfunction. Using our research as a basis, we argue that memory impairments occur when: (1) a task taps into executive deficits of OCD/checkers, and (2) accurate memory performance requires attention-dependent maintenance of bindings and/or the task has a high encoding load. Thus, executive dysfunction interferes with the accurate maintenance of complex bindings and/or fails to reduce load, impairing memory. From this we propose the

EBL classification system, which comprises executive functioning (E), binding complexity (B) and memory load (L) as central dimensions for understanding and predicting OCD memory impairments. This challenges the importance of the modality-specific view, i.e., the visuospatial- vs. verbal–memory distinction, in two important ways. First, impairments are thought to be determined primarily by poor executive functioning (E) and then by the content of the task. Second, visuospatial- compared to verbal stimulus content inherently possesses different resource requirements that are best conceived of as binding- and load-requirements.

In support of this challenge, we reviewed 58 findings across 46 studies. First, we observed that for visuospatial as well as for verbal tasks with low EBL scores, no OCD memory impairments were observed compared to controls. Second, tasks that steadily increased load (visuospatial: n-back task) or employed a high inherent load (verbal: CVLT) revealed OCD memory impairment, as the patients' executive deficits failed to match the task demands at higher load levels. Hence, across verbal and visuospatial tasks it is poor executive functioning that cannot cope with increasing cognitive demands that differentiates OCD memory performance from controls. However, we did suggest that default differences in EBL scores of verbal compared to visuospatial tasks make OCD memory impairments more likely in the latter (see Fig. 2A vs. 2B). Verbal tasks, generally, present verbal information in a format (stories, word lists that benefit from semantic clustering) that are high in load but low in binding complexity. In this case, performance is benefited by efficient executive processes that utilize existing representations in LTM, i.e., chunking according to categories reduces memory load. In contrast, basic visuospatial tasks, especially when random locations are employed, are usually less supported by LTM knowledge, so strategic executive organizing must cope with binding complexity and/or load even at low demands. This increases the number of dimensions (3 in visuospatial, i.e. EBL; vs. 2 in verbal, i.e. EL) where OCD memory impairments can occur, making visuospatial impairments more likely than verbal.

For tasks that are high in binding complexity (memory for actions, Trail-Making Task, Benton Visual Retention Task, Figural Fluency, Recurring Figures Test, Rey Complex Figure Task) consistent OCD impairments were observed across a range of measures. This can be simply surmised as an inability to organize complex visuospatial information in a manner to benefit early encoding, immediate and delayed recall and recognition. For example, in the case of RCFT performance in OCD, poor executive functioning (E) fails to reduce the load (L) by means of strategic organization, which in turn reduces the veridicality of multiple bindings (B) of the RCF representation in memory. Such a representation based on loosely interconnected feature assemblies is not only more difficult to accurately copy and recall than a tightly structured one, but it also places additional strain upon executive processes during maintenance, which are already operating sub-optimally. Further extrapolating these arguments to future studies, tasks that require complex binding of multiple and multimodal features (as in our recent studies) are also likely to tap into OCD-specific deficits due to sub-optimal executive organization of input and deficient ‘protection’ during maintenance.

The central role of executive dysfunction was further supported by the finding that targeting executive processes in OCD patients with therapeutic intervention not only reduces obsessional symptoms but also improves memory performance. We take this as evidence of a link between executive and memory impairments, anxiety, and the development of obsessions (e.g., doubt and uncertainty; “Did I turn the stove off?”) and neutralizing compulsions (e.g., checking to compensate for poor memory and high anxiety). Finally, we propose that our explanation complements existing OCD models by specifying essential cognitive mechanisms, which will hopefully help guiding future research.