Title

Modelling a Multi-Dimensional Model of Memory Performance in Obsessive-Compulsive Disorder: A Multi-Level Meta-Analytic Review.

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KK was supported by MRC grant MR/J001953/1

Abstract

Even though memory performance is a commonly researched aspect of Obsessive-Compulsive Disorder (OCD), a coherent and unified explanation of the role of specific cognitive factors has remained elusive. To address this, the present meta-analysis examined the predictive validity of Harkin and Kessler's (2011) Executive Function, Binding Complexity and Memory Load (EBL) Classification System concerning affected versus unaffected memory performance in OCD. We employed a multi-level meta-analytic approach (Viechtbauer, 2010) to accommodate the interdependent nature of the EBL model and interdependency of effect sizes (305 effect sizes from 144 studies, including 4424 OCD patients). Results revealed that the EBL model predicted memory performance; i.e., as EBL demand increases, those with OCD performed progressively worse on memory tasks. Executive function was the driving mechanism behind the EBL's impact on OCD memory performance, as it negated binding complexity, memory load, and visual or verbal task differences. Comparisons of sub-task effect sizes were also generally in accord with the cognitive parameters of the EBL taxonomy. We conclude that standardised coding of tasks along individual cognitive dimensions and multi-level meta-analyses provide a new approach to examine multi-dimensional models of memory and cognitive performance in OCD and other disorders.

Keywords: Multi-Level Meta-Analysis, Obsessive-Compulsive Disorder; Memory Performance; Executive Function; Binding Complexity; Memory Load.

General Scientific Summary

Memory performance is consistently identified as a key factor in the development and maintenance of Obsessive Compulsive Disorder (OCD). This meta-analysis tests the model of Harkin and Kessler (2011) and identifies executive function as key to understanding the memory performance of those with OCD.

Even though memory performance is a commonly researched aspect of Obsessive-Compulsive Disorder (OCD), a coherent and unified explanation of the role of specific cognitive factors has remained elusive (Hermans, Engelen, Grouwels, Joos, Lemmens, & Pieters, 2008; Snyder, Kaiser, Warren, & Heller, 2015). Historically, there has been a tendency in the literature to view verbal and visual memory/tasks as distinct entities (e.g., Boone, Ananth, Philpott, Kaur, & Djenderedjian, 1991; Zielinski, Taylor, & Juzwin, 1991; Christensen, Kim, Dysken, & Hoover, 1992; Muller & Roberts, 2005) and to focus on general (e.g. long-term) mnestic performance (McNally & Kohlbeck, 1993; MacDonald, Antony, Macleod, & Richter, 1997; Tallis, 1997; Jelinek, Moritz, Heeren, & Naber, 2006). An alternative perspective indicated a more subtle relationship, with memory impairment secondary to executive dysfunction (Greisberg & McKay, 2003), wherein deficits in executive function in conjunction with task demands differentiate the memory performance of those with OCD from controls (Olley, Malhi, & Sachdev, 2007). Extending the latter, Harkin and Kessler (2011) proposed a tripartite explanation of memory impairments in OCD; i.e., that they occur when a task taps into specific aspects of executive dysfunction, depends upon binding and/or chunking of complex information and/or places a significant load on memory capacity (Figure 1; Harkin & Kessler, 2011a). In effect, the executive functioning, binding complexity, and memory load (EBL) classification system provided a qualitative explanation of disparate memory findings. The present meta-analysis provides the next logical step, in that it aims to standardise dimensions of the EBL taxonomy and then quantify how they moderate memory performance in OCD.

The Executive-Functioning, Binding Complexity, Memory Load (EBL) Classification System

The original catalyst for the EBL classification system was the growing body of research that indicated memory impairments were secondary to executive dysfunction, with general memory capacity remaining intact (Olley, et al., 2007; Omori, Murata, Yamanishi, Nakaaki, Akechi, Mikuni, & Furukawa, 2007; Cha, Koo, Kim, Kim, Oh, Suh, & Lee, 2008; Exner, Martin, & Rief, 2009). Specifically, in a series of delayed-match to sample working memory (WM) experiments, Harkin et al. presented a range of stimuli (e.g., letters in locations; kitchen appliances on a stove) to be remembered over a short delay (see Harkin & Kessler, 2009; Harkin, Rutherford, & Kessler, 2011; Harkin & Kessler, 2011b; Harkin, Miellet, & Kessler, 2012b). Memory impairment for subclinical OCD-checkers only occurred when misleading and irrelevant information (e.g., asking the location of a letter or kitchen appliance that was not part of the original encoding set) was presented between the encoding set and the memory probe. In agreement with other research (eg., van der Wee, Ramsey, Jansma, Denys, van Megen, Westenberg, & Kahn, 2003; Ciesielski, Hamalainen, Geller, Wilhelm, Goldsmith, & Ahlfors, 2007; Henseler, Gruber, Kraft, Krick, Reith, & Falkai, 2008) an impairment in general WM capacity could not explain these findings, as across various iterations of the basic paradigm, performance was intact in the absence of a misleading or irrelevant distractor (see Harkin & Kessler, 2009; Harkin, et al., 2011; Harkin & Kessler, 2011b; Harkin, et al., 2012b). To explain the findings, Harkin and Kessler (2009) drew upon Baddeley's updated model of WM (Baddeley, 2000), wherein, in addition to the phonological loop and visuospatial sketchpad of the original model (Baddeley, 1986), Baddeley (2000) included the episodic buffer to explain the integration of temporary, multimodal representations in WM. This provided a solution to the *binding problem* (Treisman, 1996), as in reality stimuli are rarely presented in isolation, but rather are embedded as a multi-featured object (size, shape, colour, semantics, etc.), in a location, within a complex scene and context (Hinton, McClelland, & Rumelhart, 1986). The binding and maintenance of these fragile multimodal representations occur via the central executive, which explains the WM performance in the tasks of Harkin and colleagues (Allen, Baddeley, & Hitch, 2006). As such, we proposed (Harkin & Kessler, 2009) that an executive dysfunction (e.g., unsuppressed intrusive thoughts or stimuli) in those with OCD interfered with fragile multimodal bindings in the EB (i.e., letters and electrical appliances to locations), which impaired the consolidation of affected episodes into WM and long-term memory (LTM).

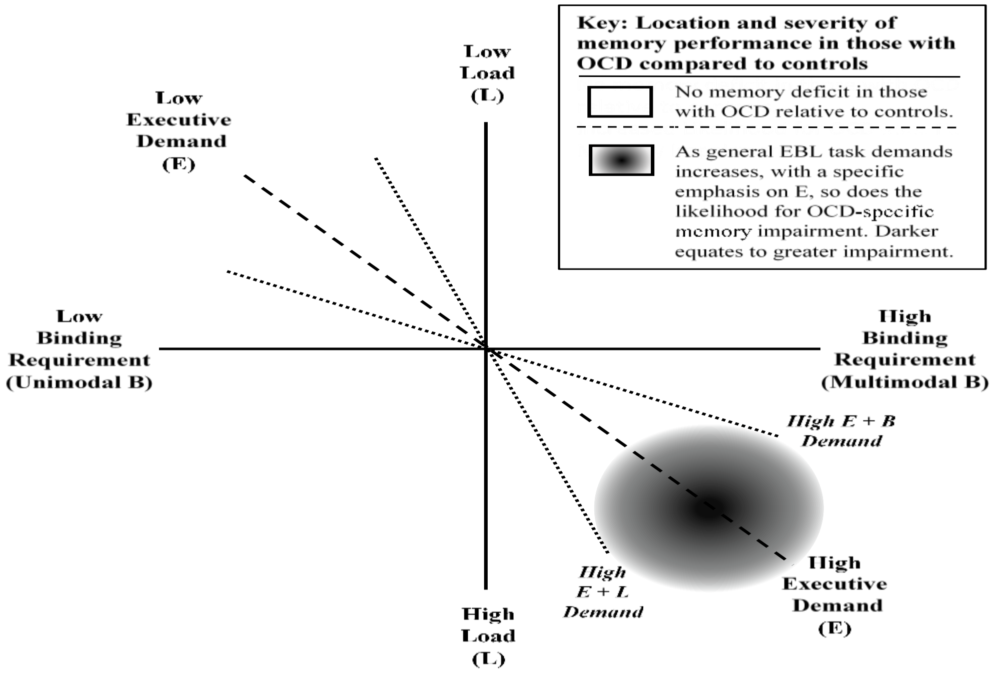

Figure 1. The Executive Function, Binding Complexity and Memory Load (EBL) Classification System, adapted from Harkin and Kessler (2011a). It is important to note that Harkin and Kessler's three EBL dimensions are not conceived of as fully orthogonal in real experimental settings (only as abstract constructs). Binding complexity may affect memory load in circumstances where large numbers of multimodal features need to be bound. Importantly, complex bindings as well as increased load will draw on executive functions when exceeding limitations (see E+L and E+B oblique dimensions in Figure), and so we propose that executive demands are the most fundamental dimension (Harkin & Kessler, 2011). Accordingly, the grey scaled circular area indicates increased likelihood for an OCD memory deficit, when load and binding complexity are high and, most importantly, when executive demands increase (darker = more likely). Thus, the orthogonal dimensions represent abstract constructs, while the oblique dimensions (as indicated by dashed lines) represent relationships in real settings: (a) the likely interrelationship between EBL factors and (b) the

centrality of executive function across binding complexity and memory load, and overall memory performance in OCD. The present meta-analysis quantifies points (a) and (b).

A Review of Reviews on Memory Performance in OCD

Many excellent reviews and meta-analyses have contributed to how we understand memory performance in OCD. We will show that they identify the parameters – either implicitly or explicitly – of memory performance in OCD as expected based on Harkin and Kessler’s (2011a) EBL taxonomy.

Systematic Reviews: Visual versus Verbal Memory Performance in OCD. Greisberg and McKay (2003) reviewed findings on attention, executive function, and memory in OCD. They reported that memory impairments (visual and verbal) in OCD are not attributable to issues of basic capacity *per se* but rather the organizational demands of the task. They then went on to explain how task demands (low versus high) explained memory performance (absent versus present, respectively) in OCD. Related to low overall EBL task demands, they stated that “when . . . tasks [demand] recall under well-structured circumstances, those with OCD . . . perform . . . similar to those without OCD" (Greisberg & McKay, 2003, p.110). Related to memory performance at high overall EBL task demands, they stated that “when tasks are less clearly defined, or when the ability to recall information . . . [requires] a combination of memory and organization . . . (as in the [Rey Complex Figure Task] RCFT), then significant impairment becomes evident” (Greisberg & McKay, 2003, p.110). From this, we infer that it is task complexity (i.e. load, bindings, executive demands) that determines affected versus unaffected memory performance in OCD.

Kuelz, Hohagen, and Voderholzer (2004) reported a varied pattern of results. To begin with, basic capacity was generally intact (e.g., WAIS-R Digit Span forward; M. D. Lezak, 1995), but the authors then reported a diverse pattern of findings for verbal fluency and higher-order executive functions like planning ability (e.g., Tower of London: TOL; Shallice, 1982). They also reported specific and consistent impairments on complex visuospatial reproduction tasks (e.g., RCFT). They proposed that memory impairments were “secondary to an inability to apply efficiently elaborated strategies” (p. 209). Wherein, those with OCD focus on irrelevant details during the encoding and copy phases of such tasks (see Harkin, et al., 2012b). Three selective reviews by Muller and Roberts (2005), Olley et al (2007), Abramovitch and Cooperman (2015) further underlined these conclusions. With inconsistent results for the recall and recognition of verbal information, and reliable deficits in the memory of complex visual material. In sum, they attributed this to visual tasks (i.e., high EBL demand) exposing the inabilities of those with OCD to generate and implement organizational strategies (executive function) to encode complex visuospatial patterns (binding complexity and memory load).

Meta-analytic Reviews: The Importance of Executive Dysfunction. As the number of meta-analysis increased, a more nuanced pattern of findings emerged. For example, in a meta-analysis of 113 studies, Abramovitch, Abramowitz, and Mittelman (2013) examined various cognitive domains (e.g., attention, executive functions, visuospatial abilities, WM) and reported the classic large versus small effect size for visual (d = -0.76) and verbal memory (d = -0.33) and medium effect sizes for a range of executive tests. They also reported that executive dysfunctions (e.g., set-shifting) were only associated with impairments in visual but not verbal memory and that impairment in visual memory "may be related to executive functioning and less with memory impairment per se" (p. 1168). A more complex pattern of memory impairments was then reported in a meta-analysis by Shin, Lee, Kim, and Kwon (2014). From 88 studies, they reported those with OCD were impaired in a range of cognitive tasks across executive, verbal and visual domains. For example, the largest impairments were again observed on visual tasks like the RCFT (g = -0.74), Tower of London (TOL: g = -0.73) and executive organization (g = -0.63); medium effects for verbal tasks (e.g., verbal learning memory-II; g = -0.42); and no significant impairments on the digit span task (g = -0.11). From this, we infer that memory impairments are most likely due to the extent that tasks tap into the executive or organizational abilities of OCD participants, as opposed to a simple dissociation between visual or verbal tasks.

Similarly, in a meta-analysis of 101 studies, Snyder et al. (2015) reported that those with OCD suffered from a global impairment (i.e., d = 0.3-0.5) across a range of executive tasks (i.e., inhibition, shifting, updating, verbal fluency, planning, general motor speed, verbal and visuospatial WM). First, 'updating' had the largest overall effect size of d = 0.71 for the n-back task, whereas, within the 'visuospatial WM' category, effect sizes for self-ordered pointing, composite score and block span were d = 0.62, 0.47 and 0.43, respectively. Second, within the 'verbal WM' domain, manipulation of verbal information had a small but significant effect (d = 0.31), whereas simple maintenance (d = 0.07) and digit span forward (d = 0.08) had very small and non-significant effects. A similar pattern was observed in a meta-analysis conducted by Leopold and Backenstrass (2015), who reported that the largest impairments were observed in tests of sustained attention, encoding, verbal and visual memory. This led them to propose a link between "applying organizational strategies to the encoding of *verbal* and *nonverbal* information … [and] poorer memory performance in OCD patients" [emphasis added] (p. 56).

Collectively, these reviews and meta-analyses highlight the following key points. (a) Memory impairment in OCD is secondary to executive dysfunction. (b) The visual versus verbal distinction might be of secondary importance to the underlying demands of the memory task. (c) Irrespective of domain (visual or verbal) memory impairment in OCD is likely when the tasks require a high degree of executive control (i.e., organizational strategies, chunking, updating, sorting) upon the task-related contents maintained in WM. (d) Memory impairment in OCD is likely when tasks are high in binding complexity and/or load and require organizational strategies in service of such task demands. (e) There is a need to examine memory performance at a domain and sub-task level, as averaging across these will obscure unique contributions of different EBL demands to memory performance in OCD.

Theoretical and Empirical Foundations of the EBL Classification System

The previous discussion suggests that the EBL taxonomy offers a parsimonious means to explain, classify and predict the often-complex pattern of memory impairments that are observed in OCD. It is important to note and as we state in Figure 1 that the dimensions are interdependent (i.e., non-orthogonal) as originally conceived in our 2011 paper (Harkin & Kessler, 2011a). That is, binding complexity might affect memory load in circumstances where large numbers of features need to be bound. Complex bindings as well as increased load will draw on executive functions when exceeding limitations, thus, executive demands are proposed as the most fundamental dimension of our taxonomy. We now detail each dimension of the EBL and highlight the theoretical and empirical foundations to each:

(1) **Executive Function.** We adopt Walter and Raffone's (2008) tripartite explanation of executive functioning of (a) *Attentional Control*: top-down selective activation of task-relevant representations and inhibition of task-irrelevant stimuli and responses (see also Adele, 2013); (b) *Maintenance and Updating*: focus on and hold task-relevant information in an active state, and when required replace with more relevant information (see unity/diversity model of EF by Miyake & Shah, 1999; Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000; Friedman, Miyake, Corley, Young, DeFries, & Hewitt, 2006); and (c) *Integration*: bind information from multimodal sources, to achieve a given task. Thus, a core function of the executive is to maintain and manipulate information in the episodic buffer (Baddeley, Allen, & Hitch, 2010). As executive impairments are an established aspect of OCD (for systematic reviews: Olley, et al., 2007; Shin, et al., 2014; Snyder, et al., 2015; Del Casale, Rapinesi, Kotzalidis, De Rossi, Curto, Janiri, Criscuolo, Alessi, Ferri, De Giorgi, Sani, Ferracuti, Girardi, & Brugnoli, 2016; Bragdon, Gibb, & Coles, 2018), it is expected that they will contribute to memory impairments in two main situations:

i. In the presence of task irrelevant distractors, those with OCD are less able to inhibit their attention to them (Coles & Heimberg, 2002), which interferes with attention-dependent bindings in the episodic buffer, and impairs subsequent memory performance (Gao, Wu, Qiu, He, Yang, & Shen, 2017).

ii. Those with OCD are less efficient in how they employ organizational strategies in the presence of complex stimuli (Kuelz, et al., 2004). This will result in memory impairments generally in visual tasks (where executive function and binding complexity demands are naturally high) and for specific verbal tasks, when executive function and binding complexity demands are similarly high. Thus, we expect that executive function will play a dominant role in the EBL's moderation of memory performance in OCD.

(2) **Binding Complexity.** Binding different, multimodal features together and maintaining these representations over time imposes a challenge that increases with the number of features,

locations and their multimodality (Fougnie & Marois, 2009). With respect to binding complexity we identify two logical and empirically validated antecedents of memory impairment in OCD: (a) the maintenance of cross-domain associations in the EB are reliant on executively directed attention (Morey, 2009; Langerock, Vergauwe, & Barrouillet, 2014); (b) those with OCD show gross impairments in executive functioning (Snyder, et al., 2015) particularly at an organizational level (Kuelz, et al., 2004); (c) which results in memory impairments for them when binding complexity is high. As such, binding complexity removes the emphasis from the visual versus verbal distinction and places a greater emphasis on the executive demands of the tasks, thus:

i. The inherently greater binding complexities of typical visuospatial tasks (e.g., multiple object-to-location bindings as observed in the RCFT) are more likely to reveal OCD impairments than typically used verbal tasks. Complex bindings are susceptible to interference and place greater demands upon the implementation of correct executive control — especially when multimodal bindings are involved (Olley, et al., 2007; Harkin & Kessler, 2009, 2011b).
ii. Verbal deficits will occur if the task relies to a similar extent upon the maintenance of complex bindings (e.g., Wechsler Logical Memory Scale-Story Recall; Chlebowski, 2011). This is consistent with a study by Cabrera, McNally and Savage (2001), who reported that those with OCD relied less on organizational strategies during the encoding of verbal information. In contrast, as simple verbal memory tasks (e.g., word list recall) are less dependent on the maintenance of complex bindings and are subserved by extant representations in LTM (e.g., embedded-process model of WM; Cowan, 1999), verbal deficits are not expected to the same extent. However, if simple verbal tasks employ OCD-threat words then this may interfere with attention directed towards the actual task (e.g., Bohne, Keuthen, Tuschen-Caffier, & Wilhelm, 2005; Jelinek, Rietschel, Kellner, Muhtz, & Moritz, 2012), impairing memory performance relative to neutral words.

(3) **Memory Load.** If WM capacity is intact in OCD (Ciesielski, et al., 2007; Henseler, et al., 2008; Harkin & Kessler, 2009, 2011b; Abramovitch & Cooperman, 2015), then impairments under high load will depend on executive function (van der Wee, et al., 2003; van der Wee, Ramsey, van Megen, Denys, Westenberg, & Kahn, 2007). An increase in load (i.e., number of chunks to retain) places greater stress upon the correct implementation of organization strategies (i.e., chunking), updating, and overall task-management (Smith & Jonides, 1999). Efficient executive control reduces the overall complexity and/or load of a representation maintained in WM (Sörqvist & Rönnberg, 2014; Simon, Tusch, Holcomb, & Daffner, 2016). 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. However, if the words create a sentence, then span can reach as high as sixteen, which far exceeds loop capacity (Baddeley, Vallar, & Wilson, 1987). Hence, chunking improves efficiency, as items are not individually maintained as a single unitary representation in WM (Miller, 1956). In this understanding, load has a conceptual and empirical overlap with binding complexity. However, it differs as it refers to the increase in cognitive load caused by more items entering WM; e.g., in sequence (e.g., *n*-back tasks) or perhaps across space (e.g., Corsi Block-Tapping Test; Corsi, 1972) as opposed to more multimodal features being required to be bound into a single chunk:

i. High load for visual (e.g., n-back task; van der Wee, et al., 2003) and verbal (e.g., WMS-Story Recall; Borges et al., 2011) tasks will similarly tax executive deficits (e.g., chunking, updating, ordering) in those with OCD, which will then result in memory impairments relative to controls.
ii. In contrast, as low load places less of a demand on executive function, memory impairments will be absent (e.g., recall of words presented in sequence, Martin, Wiggs, Altemus, Rubenstein, & Murphy, 1995) or less pronounced (e.g., digit span task, Boldrini, Del Pace, Placidi, Keilp, Ellis, Signori, Placidi, & Cappa, 2005).

The Present Meta-Analysis

The present review aims to answer a point raised by Greisberg and McKay (2003): "that a model of neuropsychological functioning in OCD must be articulated if progress is to be made in delineating specific deficit areas" (p. 112). To this end, we will quantify how the EBL system moderates memory performance in those with OCD. In addition to this, we also examined a range of methodological, clinical, demographic and sample characteristics as potential moderators of effect sizes in accord with previous research (Moher, Cook, Eastwood, Olkin, Rennie, & Stroup, 1999; Juni, Altman, & Egger, 2001) as these factors can influence the validity of effect sizes in meta-analyses. We therefore followed previous approaches employed in the OCD literature (Leopold & Backenstrass, 2015).

Methods

Selection of Studies

Included studies had to compare memory performance on at least one task between adults with OCD or OCD-type traits (e.g., checking) and healthy controls. Studies examining visual, verbal, and WM were all included. Participants with subclinical OCD were included; clinical versus sub-clinical samples were coded as a dichotomous variable. Participants with acquired OCD (e.g., following head injury) were excluded, as this group is generally considered clinically distinct from idiopathic OCD groups and illness will in most cases be associated with neurological injury (Coetzer, 2004). As hoarding disorder has recently been associated with different neuropsychological deficits than OCD (Tolin, Villavicencio, Umbach, & Kurtz, 2011), papers that included patients with hoarding as a primary diagnosis were also excluded. Healthy controls were defined as adults without any reported neurological deficits, and who were not exclusively diagnosed with another mental illness (e.g., depression), and who were not related to the OCD participants (in order to avoid tapping into a potential OCD endophenotype). Correlational studies were included if it was possible to obtain data to facilitate effect size calculation. Treatment studies were included if there were baseline memory scores available. Studies reporting only the Wisconsin Card Sorting Test were excluded, as this task is thought to mostly tap into cognitive functions other than memory (e.g., set-shifting), making it too complex of a test to directly access memory performance alone (Stratta, Daneluzzo, Prosperini, Bustini, Mattei, & Rossi, 1997). Studies had to be available in English.

Searches were conducted between October 2018 until March 2019. The search terms used to access literature was '(wash* OR check* OR hoard* OR obsessive-compulsive* OR OCD OR clean*) AND (executive OR bind* OR load* OR visual OR verbal) AND (memory)'. Keywords were developed based on previous literature; e.g., Leopold and Backenstrass (2015), and agreed upon by the first and second author. A total of 7293 studies were identified through database searching and 100 from additional sources (including an ancestry search). Full texts of 321 articles were examined, resulting in 144 to be included in the final review. The PRISMA flow chart is provided in Figure 2.

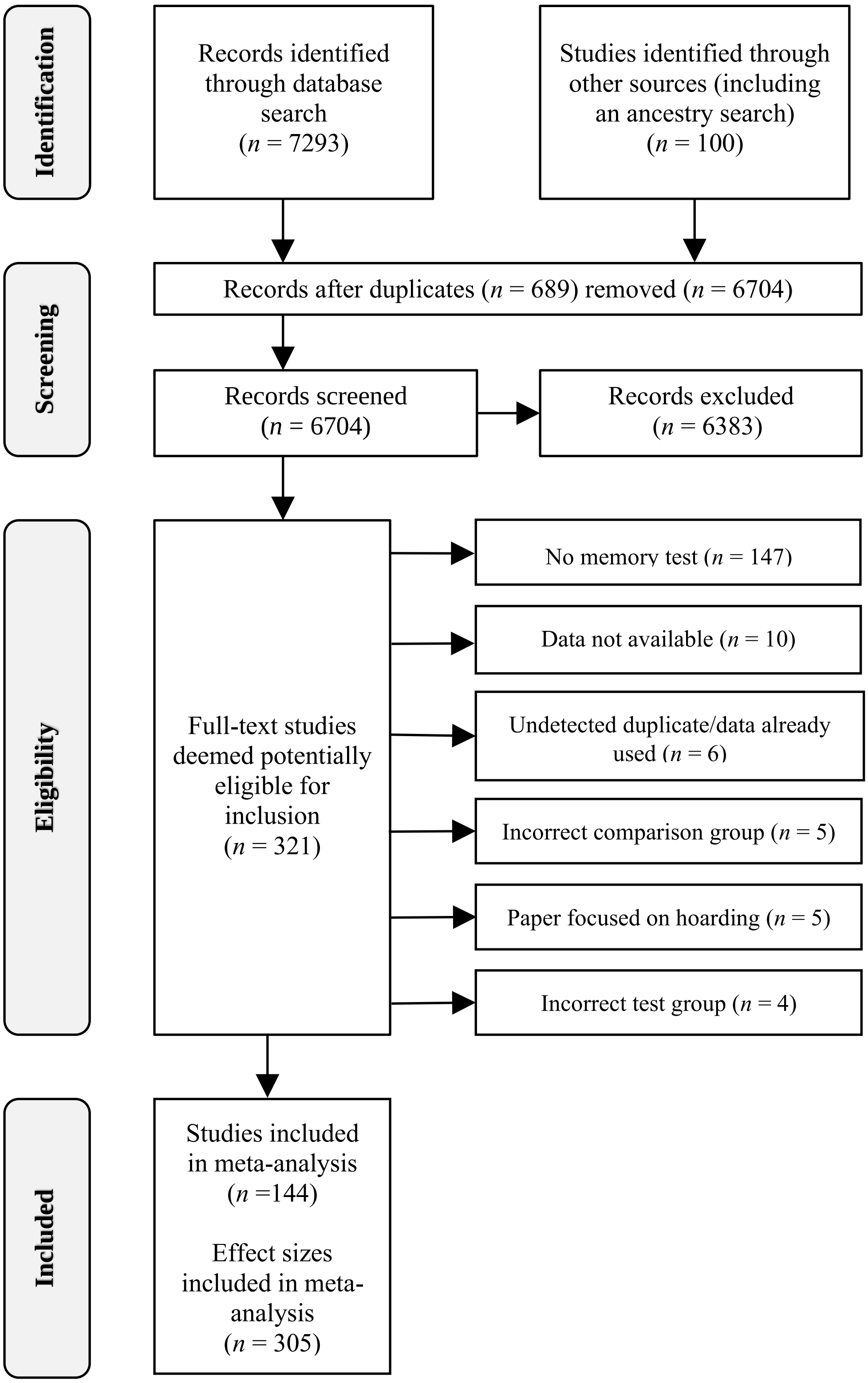

Figure 2. PRISMA flow chart detailing the database searches, number of abstracts screened, basic exclusion criteria and number, and final studies included and number of effect sizes calculated. Regarding screening, the software used (Rayyan; Quazzani et al., 2016) provides a summary of these key words used to screen out studies. According to this summary the most common reasons for excluding papers during the screening stage were as follows: wrong topic (e.g., investigations into cognitive functions in traumatic brain injury or dementia); wrong population (e.g., individuals with

schizophrenia or Alzheimer's disease); non-human investigations (e.g., rats); and paper was a meta-analysis and contained no new data.

Quantification of the EBL System

As we outlined the conceptual and empirical arguments to support the EBL system in the introduction, we now detail how we standardised each dimension for the purposes of the present review. First, we had to devise a scoring system that was not only simple but also produced meaningful ordinal differences on each of the three EBL dimensions. For example, when a given task received a high score for executive function that it differed in obvious and pragmatic ways to a task that scored lower on this dimension. To this end, for each dimension, we defined its primary features, identified when general memory impairment was likely, and how it could contribute to memory impairment in OCD. Then for each EBL dimension, we ranked each task in terms of high (3), medium (2), or low (1) demand. This addresses a limitation observed in a previous meta-analysis in memory performance in OCD, wherein "the classification of individual tasks was not based on reliable criteria" (Shin, et al., 2014, p. 1127). We outline our definitional and ordinal criterions below.

Executive Function

(a) *Primary Features*: Attention control (e.g., distractor inhibition) for the maintenance, updating, and integration of information in WM (Wolters & Raffone, 2008). (b) *General Impairment*: When task demands exceed executive function capacity or when a task taps into an aspect(s) of executive function that is impaired. (c) *Contribution to Memory Impairment in OCD*: When a task taps into an aspect of executive function that is impaired in OCD participants. Examples for each of the ordinal ratings were as follows: (a) *High*: Tasks that require higher order executive functions; e.g., deployment of organizational strategies, dual task demands. (b) *Medium*: Tasks that combine a simple task with a component that distracts executive function from the primary task; e.g., Delayed Match to Sample (DMTS) task with distractor stimuli. (c) *Low*: Executive function serves simple maintenance of information in WM; e.g., digit span.

Binding Complexity

(a) *Primary Features*: Requirement to bind numerous, complex and different (multimodal) aspects of features and maintain them in WM within space and across time (Treisman & Zhang, 2006). (b) *General Impairment*: The challenge to maintain these bindings increases with the number of features, locations and their multimodality (Fougnie & Marois, 2009). (c) *Contribution to Memory Impairment in OCD*: When those with OCD fail to deploy organizational strategies (E) to organize complex visuospatial images (and likely complex verbal information; e.g., Wechsler Logical Memory (WLM) - Story recall) into manageable parts in WM. Examples for each of the ordinal ratings were as follows. (a) *High*: Complex and numerous within- and between-object location bindings and so exceed episodic buffer capacity (i.e., approximately 3-4 feature-object-location bindings; Luck & Vogel, 1997; Langerock, et al., 2014) or organize and bind complex multimodal information into manageable chunks; e.g., RCFT. (b) *Medium*: A number of simple object-to-location bindings are present but are within the capacity of the episodic buffer; e.g., simple DMTS task. (c) *Low*: Limited to no bindings; e.g., neutral word recall.

Memory Load

(a) *Primary Features*: The amount of chunked information maintained in WM at any given time (de Fockert, Rees, Frith, & Lavie, 2001). (b) *General Impairment*: An increase in load (i.e., number of chunks to retain) places greater stress upon the correct implementation of organization strategies (i.e., chunking), updating, and overall task-management (Smith & Jonides, 1999). (c) *Contribution to Memory Impairment in OCD*: High loads (visual or verbal) will expose the deficits of those with OCD in efficiently reducing (i.e., via chunking, updating, ordering) the overall complexity or load of a representation maintained in WM. Examples for each of the ordinal ratings were as follows. (a) *High*: Complex tasks where successful performance requires efficient chunking, updating and sorting; e.g., *n*-back task (Kane & Engle, 2002). (b) *Medium*: Moderately complex tasks, where task performance may but is not entirely dependent on a reduction of load via mechanisms such as chunking. (c) *Low*: Task demands are such that stimuli can be easily chunked or organised, and/or assisted by representations in LTM (e.g., see higher WM spans for verbal versus spatial information; Langerock, et al., 2014); e.g., neutral word recall.

Total EBL Score

It is important to note that each of the EBL dimensions does not operate in isolation but rather are interdependent, a relationship that can sometimes be synergistic in nature. For example, complex visual-spatial reproduction tasks have intrinsically high binding complexity and likely load, which places a demand on executive functioning to use efficient organizational strategies to aid encoding, maintenance and recall. As such, we calculated the total EBL score for each task (i.e., Executive Function + Binding Complexity + Memory Load = Total EBL Score), this allowed us to examine the effect of the overall model for EBL on memory performance between those with OCD and controls.

The EBL taxonomy creates a set of multidimensional and interrelated moderators, which poses a challenge for traditional two-level models of meta-analysis (e.g., dependence between effect sizes). As such the present review utilises a three-level approach (for review see Cheung, 2014), recently used in the OCD literature by Fradkin, Strauss, Pereg, and Huppert (2018). This approach offers us three main methodological advantages of specific relevance to the present review. First, neuropsychological studies on OCD often use multiple measures (e.g., RCFT and California Verbal Learning Task: CVLT; Delis, Kramer, Kaplan, & Ober, 1988) from the same participants, which creates an issue of dependency between effect sizes. Multilevel meta-analysis accounts for this analytical issue and allows a combination of dependent measures from different tasks from the same group of participants (see Cheung, 2014). We provide detailed information on the analysis for the present study in the methods section. As noted, comparing effect sizes of tasks within the same domain with tasks completed by the same participants provides the analysis with greater sensitivity to identify specific deficits (Fradkin, et al., 2018). Second, Fradkin and colleagues highlighted why a meta-analysis of the proposed EBL taxonomy is possible as they noted that cognitive tasks "often include a complex set of scores and outcomes, and these complex structures are often difficult to integrate in quantitative and qualitative reviews" (p. 497). This acknowledges that cognitive dysfunction in disorders such as OCD is rarely due to one-dimensional relationships between specific cognitive components. Third, the authors also highlighted "the importance of *including different scores derived from the same task* when reviewing neuropsychological and cognitive deficits [and that] multilevel meta-analysis … allow[s] the integration of effects of complex structures" [emphasis added] (Fradkin, et al., 2018, p. 497). This emphasises the need for- as well as the suitability of the present quantitative analysis of the EBL taxonomy. A multi-level approach recognizes the complexity of memory impairment in OCD, allows the use of effect sizes from a multitude of tasks from the same participants, and provides the methodological flexibility to quantify the multi-level and interdependent set of moderators that the EBL proposes.

Domain-Specific Moderator Analyses and Sub-Task Comparisons

In the OCD literature, it is common to categorise tasks into specific domains. Here, we followed this approach to compare effect sizes for different tasks within domains, and to offer a descriptive overview of the relationship between domains and effect sizes. This also served as a *reality check* to compare our effect sizes to those reported in other meta-analysis (see Abramovitch, et al., 2013; Shin, et al., 2014; Leopold & Backenstrass, 2015; Snyder, et al., 2015). We identified eight memory dimensions and twenty-six sub-tasks and provide a full breakdown of how we categorised tasks according to our EBL criteria to a given domain in the Supplementary Materials (S3). In summary, the main dimensions were: (a) Reproduction of Complex Visual Shapes, (b) Span Sequence, (c) Spatial Span, (d) Delayed Match-to-Sample Paradigm, (e) Recall of Simple Verbal Information, (f) Recall of Complex Verbal Information, (g) Recognition Memory, and (h) Declarative and Implicit Memory.

Coding of Study Characteristics

To obtain EBL scores, all tasks were coded on three individual components; executive load, binding complexity, task load. A detailed explanation of the theoretical underpinnings of this is provided above and in Harkin and Kessler (2011a). Tasks were scored 1 through to 3, depending on how much demand was placed on the individual component: 1 indicated low to little demand, 2 moderate demand, and 3 indicated high demand. EBL scores could therefore vary between 4 and 9. Initially tasks were also assessed on emotional valence and ecological validity, but as they did not generally vary across tasks (16 and 10 effect sizes, respectively, scored above 1), they were excluded. We provide full details of the data extraction methods in Supplementary Materials (S7). A key consideration of the current examination is therefore how memory performance between patients with OCD and healthy controls (as measured by the Cohen's *d*) vary according to task demands. For reliability purposes, 10% of the data were coded blindly and independently by a second coder. Any disagreements were resolved through discussion and final agreement within the team, with virtually all discretions attributable to slight variation in calculations used. Agreement between coders was high at 98%. Intra-class correlation coefficient tests were conducted on the continuous variables EBL scores, OCD scores and Effect Size (ES). Excellent reliability was observed: the average ICC measure for EBL model was .981 with a 95% confidence interval (CI) from .964 to .990, (F(39,39) = 53.40, p < .001), ES scores were .947 with a CI from .900 to .972, (F(39,39) = 19.02, p < .001) and OCD scores were .99 with a CI from .900 to .972, (F(39,39) = 611.19, p < .001). Cohen's Kappa tests accounted for chance agreement on Task score variables represented by nominal data. Again, we observed almost perfect agreement: Executive Function (k > 0.92), Binding Complexity (k > 0.81) and Memory Load (k > 0.86) as substantial to almost perfect reliability. We provide the full ICC and Kappa statistic tables in Supplementary Materials (S9).

Computing Effect Sizes

Cohen's *d* was calculated as measure of effect size of the difference in performance on each of the memory tasks between OCD participants and healthy controls. A positive effect size indicated a memory deficit among participants with OCD, compared to control participants (e.g., Shin, et al., 2014; Leopold & Backenstrass, 2015; Snyder, et al., 2015; De Putter, Van Yper, & Koster, 2017). Where Cohen's *d* was not reported in the original study, effect sizes were either converted from other effects (e.g., *F*) or calculated manually using the Campbell Collaboration's Practical Meta-Analysis Effect Size Calculator (Wilson, 2019). As recommended by Assink and Wibbelink (2016), the variance was calculated as *SE*^2.

A number of studies provided more than one effect size, as participants had been administered several memory performance tasks during the study period, thus violating the normal requirement of independent effect size measures in meta-analysis (Rosenthal, 1986; Cheung, 2014). Dependency of effect sizes normally means that effect sizes within studies are correlated (as these are expected to show a certain similarity); this creates an overlap of information and inflates information produced by the analysis, which can result in an over-confidence in its results (Van den Noortgate, López-López, Marín-Martínez, & Sánchez-Meca, 2013; Assink & Wibbelink, 2016). Whilst it is possible to conduct sub-group analysis or aggregating effect sizes , this reduces the number of effect sizes analysed in a set, therefore limiting power of the analysis, something that is a particular concern when conducting multiple moderation analyses (Assink & Wibbelink, 2016). In the present review, these solutions would not have been suitable, since a main aim was to examine the moderating effect of task characteristics, across different memory domains and tasks.

Where correlations between effect sizes are not known, it is possible to fit a three-level meta-analytical structure. This analysis considers three levels of variance components distributed across the model, including variance between effect sizes from the same study and variance between studies; this therefore allows for an examination of how effect sizes vary between participants (level 1), outcomes (level 2), and studies (level 3) (Assink & Wibbelink, 2016). This type of approach produces a robust analysis, and has been successfully implemented in recent meta-analytical research into OCD and cognition (Fradkin, et al., 2018) and was the approach followed here.

The current analysis was conducted using the rma.va function in the Metafor package for the statistical software environment R (R Core Team, 2013); R Core Team, 2014), and recommendations of Viechtbauer (2010). A mixed-effects model was fitted, and estimation was based on the restricted maximum likelihood estimator. The analysis examined the variance distribution over the three levels, the overall effect (i.e., memory performance of those with OCD compared to controls), and the effects of a number of moderating variables. As recommended by Hox (2010) and Assink and Wibbelink (2016), moderators were first examined individually, and then combined into one analysis. This allows for initial significance screening, whilst also accounting for the possibility of variables of interest being intercorrelated, producing multicollinearity in analyses. For overall mean effects of the meta-analysis and mean effects of categorical moderators, we report Cohen’s d, and for mean effects of the continuous moderator analyses, we report standardised betas. This is in line with reporting by past research using the same statistical approach (Asskin & Wibbelink, 2016; Fradkin *et al.*, 2018). Code was adapted from Assink and Wibbelink (2016) and Harrer, Cuijpers and Ebert (2019). Visuals were created using ggplot2 (Wickham, 2016). Assessment of methodological quality occurred by entering it as a moderator of effect sizes. Publication bias was assessed using the funnel plot function (funnel) in R, as recommended by Harrer et al. (2019), and Egger’s regression coefficients (Egger, Smith, Schneider, & Minder, 1997).

Results

Data Preparation and Descriptive Analysis

Based on recommendations by Snyder et al. (2015), effect sizes 3 SD above or below the mean effect size (d = 0.50) were considered outliers, and thus excluded. On the basis of this, four effect sizes relating to two studies were removed: one relating to RCFT (Boldrini, et al., 2005), and three relating to word learning (Irak & Flament, 2009)). As recommended by Assink and Wibbelink (2016), categorical moderators were dummy coded (0: absent; 1: present), to allow for an estimation of mean effects of each category. The categorical moderator was whether the task was visual or verbal. In total, 144 independent studies were included, totalling 305 effect sizes. Thus, the mean number of effect sizes for each study was 2.13. Those included for meta-analysis are indicated with a * in the reference section (see Supplementary Materials – S1). The vast majority (*N* = 133) of studies included patients who had been formally diagnosed with OCD, and 13 included those with sub-clinical OCD. Patients were mostly (*N* = 119) diagnosed with the Yale Brown OCD Scale (YBOCS). The remaining studies (*N* = 27) utilised a variety of other measurements. Seventy-four studies included samples where all, or some of the OCD patients were medicated, whereas 33 studies included un-medicated patients only. Thirty-seven studies did not report the medications status of the participants. There was an even split between visual (*N* = 143) and verbal (*N* = 148) tasks, with a small minority (*N* = 15) combining visual and verbal elements. The mean EBL score across the individual tasks was 6.89 (median = 7, min = 4, max = 9). This indicates that overall, tasks across the sample placed considerable demand on executive function, binding complexity, and memory load.

Main and Heterogeneity Analyses

The first step of the analysis estimates the overall effect size for the memory difference between those with and without OCD, including 305 effect sizes from 144 individual studies. Across all studies the overall mean effect for the memory deficit of patients with OCD as compared to healthy control was medium-sized, $d = 0.50$, SE = 0.03, 95% CI = [.43, .57], $p < .001$. The second step of the analysis estimated the difference between within- (level 2) and between-study (level 3) variance components, an important aspect of a three-level meta-analysis. This is assessed through two separate log-likelihood-ratio tests, where the original model (with freely estimated variance at level 2 and 3 respectively) is compared to one where the variance at each of the levels is fixed. The analyses suggested that there was significant variability ($ps < .001$) between effect sizes (level 2), and also between studies (level 3), indicating that moderator analyses should be conducted (Assink & Wibbelink, 2016). Based on formulas by Cheung (2004), the total variance distribution is as follows: level 1: 28.72%; level 2: 31.88%; level 3: 39.39%. As recommended by Assink and Wibbelink (2016), moderation analyses should be conducted if less than 75% of the variance can be attributed to level 1.

EBL Moderator Analyses

A number of task-related characteristics were tested as moderators of OCD memory performance, including the EBL framework and whether the task was visual or verbal in nature. Initially, individual moderator analyses were conducted on task characteristics; this included how the task was characterised on the EBL-framework (combined EBL score, and an individual assessment of executive function, binding complexity, and load, respectively), and if the task was visual or verbal in nature. The overall model for EBL was significant: $F(1, 303) = 38.07$, $p < .001$, indicating that how a task is classified on the EBL-framework moderates the overall difference in memory performance between those with OCD and healthy controls. Specifically, as EBL demand increases, those with

OCD performed worse on memory tasks than healthy controls: *β* = 0.11, *p* < .001, 95% CI = [0.08, 0.14]. Table 1 provides the outputs of the main moderation analyses.

Table 1.

Main and Moderator Analyses

Variable	***k***	***d (se)***	***p***	**C-, C+**	**Q (*p*)**
Main Analysis	305	0.50 (0.03)	<.001	0.43, 0.57	943.86(<.001)
Variable	***k***	***β (se)***	***p***	**C-, C+**	**Q (*p*)**
EBL Model					
Full EBL model	305	0.11(0.02)	<0.001	0.08, 0.15	884.79(<.001)
Executive Function	305	0.22(0.30)	<.001	0.16, 0.28	845.90(<.001)
Binding Complexity	305	0.15(0.03)	<.001	0.09, 0.21	913.64(<.001)
Memory Load	305	-0.13(0.05)	<.001	-0.23, -0.03	933.10 (<.001)
Variable	***k***	***d (se)***	***p***	**C-, C+**	**Q (*p*)**
Type of Task					
Visual	291	0.60 (0.04)	<.001	0.51, 0.68	868.07 (<.001)
Verbal	291	0.40(0.04)	<.001	0.32, .48	868.07 (<.001)
Variable	***k***	***β (se)***	***p***	**C-, C+**	**Q (*p*)**
Participant Characteristics					
YBOCS	277	0.01(0.01)	.09	-0.002, 0.03	873.78 (<.001)
Proportion of women in OCD group	275	<.001(<.001)	.96	-.003, 003	784.16 (<.001)
Age of OCD group	288	0.02(<.001)	.002	0.01, 0.3	809.12 (<.001)

Notes: Executive Function, Binding Complexity and Memory Load (EBL) model. *k* = total number of studies included for each task. *d* (se) = Effect Size in Cohen D (standard error); *β = Standardised Beta (standard error). p* = significance. C-, C+ = confidence intervals. Q(p) = Q statistic.

Individual EBL Moderator Analyses.

As for the individual components of the EBL framework, executive function was a significant moderator on memory performance, *β* = 0.22, *p* < .001, 95% CI = [0.16, 0.27]. Specifically, as executive function demand increased, so did the memory deficit for OCD participants. Additionally, increased binding complexity of the memory task also increased OCD memory deficit: *β* = 0.15, p < .001, 95% C = [0.09, 0.21]. Interestingly, the moderating effect of memory load went in the opposite direction, with increases in load leading to better memory performance of those with OCD as compared to healthy controls, *β* = - 0.13, *p* < .001, 95% CI = [-0.23, -0.03]. Figure 2 provides visual plots of the moderating effect between the EBL model and individual components (i.e., executive function, binding complexity, memory load) and memory performance in OCD.

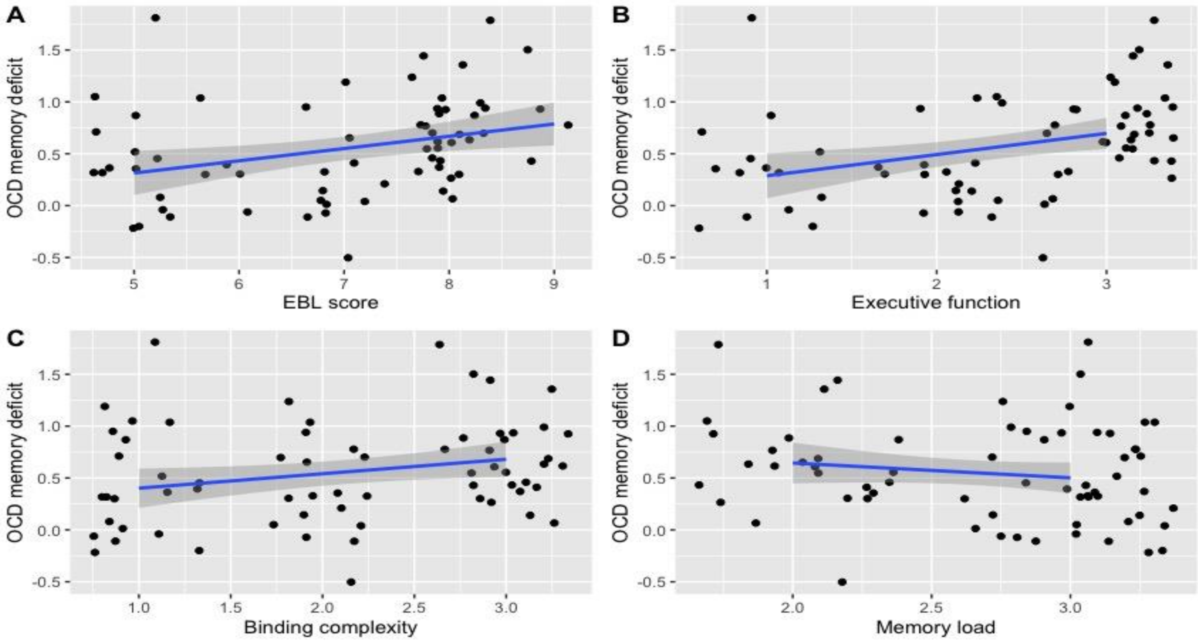

Figure 2. Visualisation of Individual Moderation Effects.

Visual versus Verbal Moderator Analysis

A moderator analysis was then performed on the type of memory task that was classified as either visual or verbal in nature. Due to their relative scarcity, memory tasks that combined visual and verbal elements were excluded, leaving a final sample of 291 effect sizes. First, verbal tasks were classified as the reference category, and visual tasks tested against this. The overall mean effects for visual and verbal tasks were d = 0.60, SE = 0.04, 95% CI = [.51, .68, p < .001, and d = 0.40, SE = 0.04, 95% CI = [-.32, -.48], p < .001, respectively. Thus, there was a greater memory deficit among those with OCD when visual tasks were used. Figure 3 illustrates the interaction between type of task (visual versus verbal) and executive function. This suggests that there is a larger memory impairment on visual tasks (as compared to verbal tasks), as associated with greater demand on executive function. It is possible this goes some way towards explaining why generally; those with OCD perform worse than controls on visual tasks, but not always on verbal tasks.

Combined Moderator Analysis

Variables relating to task characteristics were then combined into one analysis, as per the recommendations by Hox (2010). As it is expected that there will be a degree of confound among the task characteristics, this allows for an examination of whether individual moderators remain significant when examined together. Therefore, we combined whether the task was visual or verbal with all of the individual EBL components (executive function, binding complexity, and memory load) for one model. The full model was significant, $F(4,286) = 14.54$, p < .001. Importantly, only executive function remained a significant moderator in this context, β = 0.23, 95% CI = [.14, 0.32]. Therefore, binding complexity, memory load and, whether the task was visual or verbal in nature were no longer significant when tested in the context of executive function. Thus, executive function appears to hold the main task-related moderating impact on the memory impairments in those with OCD and differentiates them from healthy controls. As is plotted in Figure 3 visual tasks appear to place a considerable demand on executive function, and also produce greater memory differences for those with OCD.

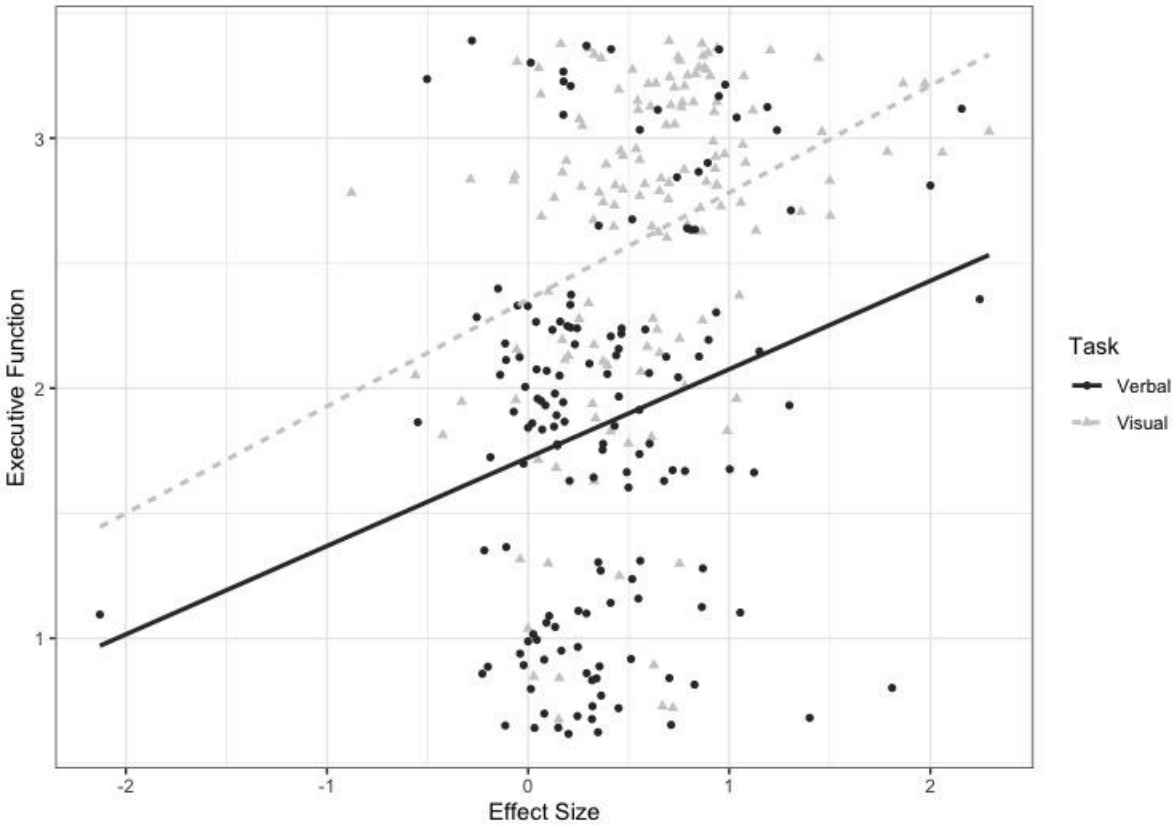

Figure 3. Moderating Effect of Executive Function and Type of Task on the OCD Memory Deficit. The graph illustrates larger memory impairment on visual tasks (as compared to verbal tasks), as associated with greater demand on executive function.

Domain-Specific Moderator and Sub-Task Analyses

We conducted moderation analysis for each of the previously identified eight main memory domains, with only executive function entered into the analysis, as in the previous full model it was the only dimension to remain significant. In line with the overall analysis, executive function remains a considerable moderator in tasks that loads more heavily onto this dimension; e.g., complex visual reproduction tasks $\beta = 0.78$, $p < .001$, 95% CI = [0.66, 0.90]. Whereas, for tasks that place less demand on executive function (e.g., implicit and declarative memory tasks; $p = 0.21$ and 0.45, respectively), it does not moderate effects, importantly, they also generally report less differential memory performance between those with OCD, and those without. In addition, for illustrative purposes we calculated EBL scores and effect sizes for individual tasks within each memory domain. We provide full details of these analyses and tables in the Supplementary Materials (S4) and expand upon them within the discussion.

Participant Characteristics

Moderation analyses for participant characteristics (percentage of women $\beta = 0.001$, $p = 0.84$, 95% CI = [-0.01, 0.02], participant YBOCS score $\beta = 0.01$, $p = .06$, 95% CI = [-.002, 0.03]) were non-significant, apart from the analysis on age. Specifically, as age increased, those with OCD performed worse on memory tasks than healthy controls: $\beta = 0.02$, $p < .01$, 95% CI = [0.01, 0.03], although it should be noted that the effect was very small.

Study Quality and Publication Bias

All studies were given a methodological quality score, with a mean quality score for the overall sample of 21.94 (median = 23.00, min = 2, max = 29). The potential maximum score was 30, indicating an overall good quality of methodology of included studies. To examine whether study quality was associated with overall result, a moderator analysis with the methodological quality score indicated that the methodological quality was not associated with overall results: $\beta = 0.01$, $p = 0.24$, 95% CI = [-0.007, 0.03], nor did it significantly contribute to the moderation model: $\beta = 0.001$, $p = 0.90$, 95% CI = [-0.02, 0.02].

Although there is considerable symmetry among the majority of studies, a small number fell outside of the funnel (see Supplementary Materials – S2). The Egger's regression coefficient was significant: $\beta = .60$, $p < .01$, 95% CI = [0.52, 2.68]. In this instance, Duval and Tweedie's (2000) trim and fill approach is suggested, however, it has been observed to drastically underestimate effect sizes when between-study heterogeneity is large (Peters, Sutton, Jones, Abrams, & Rushton, 2007). Heterogeneity in the present meta-analysis we attribute to variance in sample sizes across studies (i.e., total n: 20 to 410 participants; Simonsohn, 2017), a large number of studies ($k = 144$) and numerous interrelated effect sizes (i.e., 305 data points) for 28 individual memory tasks from 9 memory domains. Thus, we did not conduct additional transformations on our data, especially when our original effect sizes (Table S2) were comparable to those reported in previous meta-analyses of memory performance in OCD (see Abramovitch, et al., 2013; Shin, et al., 2014; Leopold & Backenstrass, 2015; Snyder, et al., 2015).

Discussion

Memory performance in OCD is a commonly researched aspect of this disorder, which has made it the subject of numerous selective (Greisberg & McKay, 2003; Kuelz, et al., 2004; Muller & Roberts, 2005; Olley, et al., 2007; Abramovitch & Cooperman, 2015) and meta-analytic reviews (Abramovitch, et al., 2013; Shin, et al., 2014; Leopold & Backenstrass, 2015; Snyder, et al., 2015). Despite these excellent reviews and associated research, the field has yet to provide a unified and coherent model to understand memory impairment in OCD. This, in part, is attributable to an emphasis on memory performance between specific memory domains (e.g., visual versus verbal) and associated tasks (e.g., California Verbal Learning Task [CVLT] versus RCFT, respectively). As a solution, the present meta-analysis takes a novel approach to memory impairment in OCD, wherein we standardise specific task features as set out in the original EBL classification system (Harkin & Kessler, 2011a). We observed that the EBL taxonomy had explanatory power for several aspects of memory performance and deficits in OCD.

Predictive Validity of the EBL Model

The EBL model had predictive validity for memory performance in OCD. Specifically, as EBL demand increases, those with OCD had poorer memory performance relative to controls. We observed a medium-sized (d = 0.50) memory deficit in those with OCD, which is comparable to the overall effect sizes reported in previous meta-analyses on memory performance in OCD (Abramovitch, et al., 2013; Shin, et al., 2014; Snyder, et al., 2015). The total number of data points (305 effect sizes) that contributed to our overall EBL model moderation analyses adds to our confidence in our results. Together, these points support the assertion that the pattern of memory impairments we observe are not due to spurious coding or issues of study inclusion but rather the relationship between specific dimensions of the EBL system and memory performance in those with OCD. This gives us confidence that the present results have gone some of the way to satisfy a point raised by Greisberg and McKay (2003), in that we have a model of memory performance in OCD, that allows us to delineate deficits in specific areas.

Individual EBL Components

One of the strengths of the present approach is that we were able to isolate the effects of each EBL dimension on memory performance. Our results indicate that as executive function and binding complexity increases, so does memory impairment. In explanation, binding of complex stimuli relies upon attention to the encoding, maintenance, and retrieval of object-object and object-location bindings (Hinton, et al., 1986; Morey, 2009; Langerock, et al., 2014). However, when this attention is interfered with or insufficient to the demands of the task, then memory impairment follows (Fougnie & Marois, 2009). In line with a body of research (e.g., Head, Bolton, & Hymas, 1989; Enright & Beech, 1993; Bohne, Savage, Deckersbach, Keuthen, Jenike, Tuschen-Caffier, & Wilhelm, 2005; Penades, Catalan, Andres, Salamero, & Gasto, 2005) this identifies executive impairments as an established feature of OCD (see Snyder, et al., 2015 for a meta-analysis on gross EF impairments in OCD), suggesting that memory impairments are secondary to executive dysfunction (e.g., Olley, et al., 2007), and stimuli that are high in binding complexity will expose the deficits of those with OCD to encode such stimuli (visual or verbal) in an efficient manner (VanRullen, 2009). In contrast, our findings with respect to memory load were contrary to our expectations; i.e., increases in load lead to better memory performance in the OCD group, although this effect was, as with binding complexity, relatively small. To explain this, we highlight a critique of cognitive research in OCD by Ouimet, Ashbaugh and Radomsky (2019): “methods are rarely process-pure and often conflate cognitive processes with measure outcomes … as if the outcome and the underlying cognitive process are one and the same” (p. 24). Therefore, our findings may reflect a discrepancy between how we conceptually defined load (i.e., a function of stimulus complexity due to exectuvie function and binding complexity demands; Simon, et al., 2016) and then actually scored a task with respect to load; e.g., more as a function of basic and isolated WM capacity (de Fockert, et al., 2001). However, it should be noted that when combined into one analysis, executive function was the only EBL component which remained significant, something which suggests that binding complexity and memory load may be of more minor importance. This is further discussed below.

Visual versus Verbal Tasks

Consistent with a body of literature (Abramovitch, et al., 2013; Shin, et al., 2014; Snyder, et al., 2015), we observed that OCD participants had greater impairment in visual (d = 0.60) compared to verbal tasks (d = 0.40), and had the classic effect size difference for the RCFT (d = 0.86) and the CVLT (d = 0.37) (Abramovitch, et al., 2013). However, we conclude that visual tasks place greater demands on OCD patients than verbal tasks in concordance with aspects of the EBL model; this goes some of the way to explain why those with OCD generally perform worse than controls on visual tasks, but not always on verbal tasks (see reviews by Muller & Roberts, 2005; Olley, et al., 2007; Abramovitch & Cooperman, 2015). We further conclude that executive function likely explains this pattern. In that, the performance of verbal tasks (e.g., word lists in CVLT) and the maintenance of verbal information in WM are likely supported via existing representations in LTM (see Embedded Process Model of WM; Cowan, 1999), which tempers the incorrect deployment of executive functions (i.e., attention) to task demands that we commonly observe in OCD (for review see Collette, Van der Linden, & Ponceret, 2000). In contrast, such bottom-up LTM representations are not so readily available to support the maintenance of novel visuospatial representations in WM (e.g., geometric shapes in the RCFT). Rather, the veridicality of fragile object-location bindings in WM are dependent on focused and uninterrupted executive functions (i.e., selective attention; Allen, et al., 2006; Fougnie & Marois, 2009). We underline the significance of executive function demand across visual and verbal memory performance in OCD in the next section.

The Importance of Executive Function

Executive function was one of the strongest and theoretically most interesting predictors of memory performance in those with OCD. First, a pivotal finding was that executive function negated the impact of the visual versus verbal memory task difference in those with OCD. This later finding is important as it highlights that it is the executive demands of a task and not the visual or verbal description of a task that determines memory performance in OCD. This validates an insight of Leopold and Backenstrass (2015) who drew a relationship between an impairment in applying executive strategies to efficiently encode *visual* and *verbal* information and subsequent memory deficits (see Savage, Baer, Keuthen, Brown, Rauch, & Jenike, 1999; Deckersbach, Otto, Savage, Baer, & Jenike, 2000; Shin, et al., 2014). Second, executive function was the strongest (and, when combined, the only remaining significant) predictor of memory performance as compared to the combined EBL model, individual binding and load dimensions, and visual versus verbal task-type, indicating that executive function is the driving mechanism behind the EBL's impact on memory performance in OCD. This was expected based on the original EBL conceptualisation by Harkin and Kessler (2011a), where executive function was the dominant dimension in the interdependent EBL model. Nevertheless, conforming to the oblique dimensioning of EBL, binding complexity as a reflection of the multimodality of memory chunks, might additionally contribute towards explaining OCD memory deficits in certain tasks (Table 2), especially those where complex multimodal representations increase demands on executive function. Importantly, our current finding serves to explicitly quantify the often cited observation that memory impairment in OCD is in fact secondary to executive dysfunction (Greisberg & McKay, 2003; van der Wee, et al., 2003; Kuelz, et al., 2004; Olley, et al., 2007; Abramovitch, et al., 2013), and highlights the importance of our novel coding and multi-level approach. That is, if we had focused on the traditional visual-verbal distinction, our analysis would not have uncovered the subtle, underlying and significant impact of executive function across a range of tasks generally and for the visual-verbal distinction specifically.

Memory Domains.

We conducted domain-specific moderator analysis with executive function only (full analysis in Supplementary Materials – S4). In general, for the domains that load heavily on executive function (e.g. reproduction of complex visual stimuli, span-sequence, and recall of complex verbal information), the memory performance of those with OCD was impaired relative to controls. In contrast, for domains (e.g., implicit and declarative memory domains) that loaded less heavily on executive function, then there was less of a pronounced difference in memory performance between OCD participants and controls. It is interesting to note that the executive demands of a given domain moderated effect sizes more distinctly than a general dissociation between the visual and verbal domain. For example, executive function moderated poorer memory performance in OCD patients on the reproduction of complex visual images and recall of complex verbal information but not on the DMTS, spatial-span or recall of simple verbal information domains.

Within each of these main memory domains, we categorised relevant tasks and averaged effect sizes accordingly (see Supplementary Materials – S3 & 4). This provided a further descriptive level of analysis to that of the previous domain-specific moderator analyses and provided a comparative *reality check* of effect sizes to those reported in other meta-analysis. First, we observed that effect sizes for the visual-reproduction (d = 0.88), RCFT (d = 0.86) and the Wechsler Memory Scale - Visual Reproduction (d = 0.54) tasks were comparable to other meta-analytic reviews (e.g., Abramovitch, et al., 2013; Shin, et al., 2014; Leopold & Backenstrass, 2015; Snyder, et al., 2015). Considering the strong moderating effect of executive function for these tasks, we conclude that OCD patients fail to organize complex geometric shapes in an efficient manner during encoding (see Penades, et al., 2005). Second, for the tasks that made up the span-sequence domain, we observed a range of effect sizes for the *n*-back (d = 1.13), symbol (d = 0.67) and digit (d = 0.31) tasks. We highlight the reliability of these findings, as a meta-analysis by Snyder et al. (2015) also reported the largest impairment of those with OCD on the *n*-back, and the small effect size for digit span matches that of a meta-analysis by Shin et al. (2014). In the domain of spatial span, we observed medium sized memory deficits in OCD participants in the Tower of London (TOL; d = 0.74), Self-Ordered Sort Task (SOST; d = 0.64) and Corsi-Block Tapping Task (CBTT; d = 0.50). This pattern and magnitude of effect sizes for the TOL and CBTT were similar to those reported in the meta-analysis by Shin et al. (2014). Based on our inclusion criteria for these tasks, we conclude that those with OCD suffer from a general impairment on the maintenance and potential manipulation of visuospatial representations in WM.

We draw support for the argument that WM capacity is intact in OCD (Ciesielski, Hamalainen, Lesnik, Geller, & Ahlfors, 2005; Ciesielski, et al., 2007; Henseler, et al., 2008; Exner, Kohl, Zaudig, Langs, Lincoln, & Rief, 2009; Abramovitch, et al., 2013) from the fourth domain that included two similar DMTS tasks. Specifically, we observed that for a basic storage task there was little difference between OCD patients and controls (d = 0.14). In contrast, when the same DMTS task has a distractor stimulus between encoding and the memory probe, then those with OCD suffered from considerable memory impairment (d = 0.62). This helps to underscore the point that any significant deficits in memory are not attributable to issues of capacity *per se* but rather the correct deployment of executive functions (i.e., inhibition of distractors; Enright & Beech, 1993; Enright, Beech, & Claridge, 1995) within WM.

The recall of verbal information in the simple and complex domains revealed an interesting pattern. First, across eight tasks, effect sizes ranged from large (d = 0.97 for recall of complex verbal information), medium (d = 0.65 for WLM – story recall), and none (d = 0.02 for the recall of neutral words). This indicates that verbal memory performance in OCD is dependent on the task. In addition, within the category of simple recall of verbal information, OCD participants suffered from a medium impairment for threat words (d = 0.46) compared to small and negligible impairments for cued (d = 0.22) and neutral (d = 0.02) word recall, respectively. This pattern again indicates that WM is generally intact in OCD, yet in these tasks, the simple introduction of a threatening word interferes with the accuracy of its maintenance in WM to the detriment of subsequent memory recall. Again, in the domain of recall of complex verbal information, we observe the largest impairments for tasks (i.e., combined verbal tasks, WLM – story recall) that place a premium on executive function (e.g., semantic processing) as observed in the previous moderator analysis.

In the recognition domain, we observed that those with OCD had medium deficits for visuo-spatial (d = 0.57) compared to small impairments for object (d = 0.27) and verbal (d = 0.20) recognition. However, as executive function did not moderate the effects of memory performance for those with OCD in this domain, we cannot conclude specifically on how executive function contributes to each of these tasks other than to say the findings matched those observed previously (Savage, Keuthen, Jenike, Brown, Baer, Kendrick, Miguel, Rauch, & Albert, 1996).

To our knowledge, this is the first time that declarative and implicit memory domains have been subject to meta-analytic review. For those with OCD, prospective memory (i.e., remember to perform an action) showed a moderate impairment (d = 0.43) relative to controls. In an experimental study, Yang, Peng, Wang, Geng, Miao, Shum, Cheung, and Chan (2015) proposed that deficits in prospective memory in OCD may be attributable to impairments in executive functions such as updating and mental-shifting. Snyder et al. (2015) identified updating as significantly impaired in OCD, suggesting that such prospective memory impairments are secondary to executive dysfunction. Source, false and procedural memory resulted in small to no memory impairments (d = 0.30, 0.10, -0.04, respectively). Interestingly, Shahar et al. (2017) reported that while procedural memory was intact in OCD (d = 0.10), they did observe 'compensatory' impairments in their ability to identify the stimulus. We propose that if procedural memory tasks were to employ stimuli that tax executive function and binding complexity, then we may observe impairments for those with OCD.

Limitations and Future Research

The present review validates the EBL system to understand memory performance in OCD. However, we identify limitations within the present study, and where appropriate propose potential solutions via the avenue of future research. First, due to a lack of studies with OCD-subtypes (e.g., 13 studies in the washer versus checker meta-analysis of Leopold & Backenstrass, 2015), and comorbidities, it was not possible to conduct moderator analyses that compared, for example, checkers versus cleaners or the impact of depression or anxiety on memory impairment in OCD. Another issue in this meta-analysis and others is differences in how to categorise a given task. For example, Shin et al. (2014) defined the digit span task as a measure of attention, whereas using our inclusion criteria (i.e., the memorization of items a given sequence) we categorised it within the span-sequence domain. We argue that as we classified tasks based on defined criterions, we have some confidence on the internal validity of how we categorised tasks (see Shin, et al., 2014). In light of this, we suggest that there is a need to provide reliable and valid task-scoring frameworks that future meta-analysis and experimental studies can employ. This would create a body of literature that characterises tasks in a congruent manner, which in turn would improve the ability to compare the outcomes of different studies and to conduct meta-analysis in any given area.

A further shortcoming of many studies that became evident throughout the preliminary search and coding of studies was that very few employed emotionally relevant or ecologically valid stimuli (e.g., Tolin, Abramowitz, Brigidi, Amir, Street, & Foa, 2001; Harkin, et al., 2011). Therefore, while we initially assessed tasks on emotional valence and ecological validity, but as they did not generally vary across tasks, they were excluded from further analyses. As such, while we observed an informative pattern of memory performance for those with OCD, we are limited to the extent that we conclude on memory performance for idiographic stimuli in OCD relevant settings. Indeed, some studies that have utilized ecologically valid stimuli have reported memory biases in favour of threat-relevant stimuli in OCD (Constans, Foa, Franklin, & Mathews, 1995; Radomsky & Rachman, 2004). In future, if more studies employ emotionally relevant or ecologically valid stimuli, then a subsequent meta-analysis comparing them to traditional stimuli (e.g., RCFT) in the context of the EBL taxonomy would be informative. Doing so would help close the gap between empirical research and clinical practice as identified in the aptly titled paper of Ouimet et al. (2019): "Hoping for more: How cognitive science has and hasn't been helpful to the OCD clinician." For example, we identified executive function and visual memory as key areas of impairment in OCD across a range of different tasks and participants. This suggests that cognitive retraining of executive function in the visual domain may boost the effectiveness of commonly used interventions (i.e., Exposure and Response Prevention). For example, it has been observed that you can retrain those with OCD to focus on the whole and not the parts of a simple visual image (Buhlmann, Deckersbach, Engelhard, Cook, Rauch, Kathmann, Wilhelm, & Savage, 2006). This may serve as a simple and safe primer for OCD patients to be open to interventions that encourage inhibitory learning within an exposure and response prevention paradigm; i.e., not only is a feared object of an obsession safe but so too is the emotional response that accompanies it (Jacoby & Abramowitz, 2016). As such, we propose that the investigation of executive retraining as an adjunct to in-vivo methods would be an interesting avenue of future research. In addition, the extent that established features of OCD; e.g., cognitive (e.g., intolerance of uncertainty; Tolin, Abramowitz, Brigidi, & Foa, 2003), meta-cognitive (e.g., confidence in memory; Tolin, et al., 2001), attitudinal (e.g., inflated personal responsibility; Salkovskis, Wroe, Gledhill, Morrison, Forrester, Richards, Reynolds, & Thorpe, 2000) and emotional factors (Thorsen, Hagland, Radua, Mataix-Cols, Kvale, Hansen, & van den Heuvel, 2018) interact with individual or collective dimensions of the EBL system is unknown and requires investigation in future research.

Lastly, we propose the following to counter the inherent weakness of inferring cognitive processes from outcome measures (see Ouimet, et al., 2019 discussed above). First, a possible solution is to infer causality via the manipulation of dimensions of the EBL in non-OCD participants (see van den Hout, van Dis, van Woudenberg, & van de Groep, 2019 for a review on such methods), and measure changes in memory performance, memory confidence, and obsessional-compulsive symptoms. Second, neuroimaging can inform the cognitive-emotional processes that contribute to task performance, even when outcome measures are uninformative. For example, Henseler et al. (2008) reported no differences in the performance of OCD patients and controls on simple tests of

WM. Based on this behavioural finding alone, one could conclude that as there is no difference in the outcome measures, then there is no difference in the cognitive processes of these two groups. However, Henseler and colleagues also conducted concurrent brain imaging and reported that those with OCD had a greater activation in brain regions associated (i.e., compensatory processes) with basic rehearsal and maintenance. Applying this to the EBL, using functional imaging in a synchronous manner with specific manipulations in EBL dimensions, could inform the literature if memory performance in OCD is attributable to processes of: WM maintenance (e.g., dorsolateral PFC; Ranganath, Cohen, & Brozinsky, 2005), organizational strategies (e.g., orbitofrontal cortext; Choi, Kang, Kim, Ha, Lee, Youn, Kim, Kim, & Kwon, 2004), binding (e.g., prefrontal cortex; Prabhakaran, Narayanan, Zhao, & Gabrieli, 2000), load (e.g., frontoparietal network; Tomasi, Chang, Caparelli, & Ernst, 2007), error monitoring (e.g., anterior cingulate cortex; Koch, Wagner, Schachtzabel, Peikert, Schultz, Sauer, & Schlosser, 2012) or emotional decision making (e.g., striatum; Crittenden, Tillberg, Riad, Shima, Gerfen, Curry, Housman, Nelson, Boyden, & Graybiel, 2016).

Conclusion

The present three-level meta-analysis of 305 effect sizes from 144 studies indicates that the EBL taxonomy (Harkin & Kessler, 2011a) has explanatory power in explaining the memory performance of those with OCD. Specifically, executive function appears to be the driving mechanism behind the EBL framework’s predictive power for OCD memory performance, and tellingly, negated effect size differences between visual and verbal tasks and the impact of binding complexity and memory load in those with OCD, when executive demands were controlled. This highlights that it is the executive demands of a task and not the visual or verbal description of a task, which determines memory performance in OCD. Domain-specific moderator analyses and comparison of sub-task effect sizes were also generally in accord with the cognitive parameters of the EBL taxonomy. We conclude that our novel approaches to coding tasks along individual cognitive dimensions and the use of multi-level statistical analyses provides a standardised means to examine multi-dimensional models of memory and cognitive performance in OCD and other disorders.

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