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Top-Down and Bottom-Up Contributions to Memory Performance in OCD: A Multilevel Meta-Analysis With Clinical Implications

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Despite extensive coverage of a relationship between memory performance and executive function in the obsessive-compulsive disorder (OCD) literature, the relative contributions of specific aspects of executive control have remained elusive. We, therefore, extend our previous multilevel meta-analysis (Persson et al., 2021), where demand on executive function was the most significant determinant of memory deficits in OCD, and provide a finer-grained analysis of executive control via a segregation into top-down (attentional control, maintenance and updating, planning) and bottom-up (perceptual integration, perceptual salience) contributions. Our multilevel meta-analytic approach allowed us to accommodate the interdependency of 255 effect sizes from 131 studies, totaling 4,101 OCD patients. Results revealed that maintenance and updating (top-down) and perceptual integration (bottom-up) predicted memory performance generally, and specifically in those with clinical OCD. Exploratory analyses suggested that this effect may be somewhat different among subclinical OCD groups; however, these findings should be considered with conceptual and analytical caveats in mind. We explain these results via deficient sensory (perceptual integration) and working memory (maintenance and updating) gating mechanisms and propose a model to accommodate their expression in OC symptoms. In conclusion, our meta-analysis has expanded understanding of cognitive performance in OCD and identifies the possibility of untapped cognitive targets for intervention.

General Scientific Summary
Deficits in executive function and memory are common in OCD. We identify and test two novel frameworks, top-down and bottom-up, to explain memory deficits in OCD using a multilevel meta-analysis. We found that maintenance and updating, as well as perceptual integration, predicted memory deficits in OCD, where in turn we explained these via deficient sensory and working memory (WM) gating mechanisms, respectively. Our meta-analytical results and explanations may inform future novel interventions.

Keywords: OCD, executive function, memory, top-down, bottom-up

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Obsessive-compulsive disorder (OCD) is often characterized by an inability to perform everyday tasks (e.g., turning off the oven, washing hands) simply and efficiently, with memory impairments often associated with those tasks (Abramovitch & Cooperman, 2015; Greisberg & McKay, 2003; Olley et al., 2007; Tallis, 1995). Cognitive explanations propose that those with OCD focus on

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stimulus-driven processes (e.g., irrelevant features) to the detriment of task-related goals (e.g., accurate memory performance; Chen et al., 2018; Fradkin et al., 2018; Gürsel et al., 2018). Empirical evidence in three main areas supports this. (a) Those with OCD show impairments in their ability to inhibit attention to irrelevant and distracting features (Dupuy et al., 2013; Norman et al., 2016). (b) They consistently fail to implement efficient organizational strategies in the performance of complex tasks (Deckersbach et al., 2004; Savage et al., 2000). (c) Impairments in inhibition and organization are associated with deficits in the memory performance of those with OCD (Harkin et al., 2011; Harkin & Kessler, 2009; M. S. Shin et al., 2004).

Furthermore, a series of excellent reviews unifies these three main points as they identify the importance of executive dysfunction (e.g., inhibitory and organizational impairments) in OCD generally (e.g., Del Casale et al., 2016; Olley et al., 2007; N. Y. Shin et al., 2014; Snyder et al., 2015) and memory impairments specifically (e.g., Abramovitch et al., 2013; Leopold & Backenstrass, 2015; N. Y. Shin et al., 2014). Moreover, in our recent multilevel meta-analysis, we reported that demand on executive function was the driving mechanism of poor memory performance in those with OCD, when compared to healthy controls (Persson et al., 2021). Due to our unique approach to coding individuals tasks, we were able to concretely conclude that demand on executive function was the strongest predictor of memory performance in OCD as it rendered binding complexity, memory load, and visual or verbal task differences nonsignificant (for theoretical exposition, see Harkin & Kessler, 2011a).

Considering the relationship between executive function and memory performance in OCD, the present meta-analysis provides the next logical step by further segregating executive contributions. Specifically, we standardize individual dimensions of executive control in terms of top-down (i.e., attentional control, maintenance and updating, planning) and bottom-up (i.e., perceptual integration; perceptual salience) frameworks and quantify how they moderate memory performance in OCD. This approach satisfies an observation of Snyder et al. (2015) who posited that despite those with OCD potentially suffering from global impairments in executive function, a more parsimonious explanation may be that they suffer from specific and independent impairments in various aspects of executive function. Furthermore, the authors highlighted the importance of the top-down and bottom-up distinctions and suggested that those with OCD suffer impairments in their "ability to actively maintain task goals [top-down] and use this information to effectively bias lower-level processes [bottom-up]" (Snyder et al., 2015, p. 15).

Together, these points highlight a gap within the literature in terms of the manner that specific subcomponents of executive function may predict memory performance in OCD. Within this investigation, we aim to identify new targets for interventions in the treatment of this disorder and hope to answer the call "for clinically-applicable cognitive science" for OCD by Ouimet et al. (2019, p. 25).

The Executive-Memory Relationship in OCD

A consistent finding in OCD is of intact working memory (WM) capacity across a range of modalities (e.g., visual, verbal, procedural, and ecologically relevant stimuli; Ciesielski et al., 2007, 2012; Harkin et al., 2011; Harkin & Kessler, 2009; Henseler et al., 2008; Shahar et al., 2017). A pattern that is also clearly supported in meta-analytic research; for example, Snyder et al. (2015) reported that basic measures of memory capacity (i.e., maintenance and digit span) did not significantly differ between those with OCD and controls (see Leopold & Backenstrass, 2015; N. Y. Shin et al., 2014).

In contrast, when we observe poor memory performance in OCD, it is consistently "related to executive functioning and less with memory impairment per se" (Abramovitch et al., 2013, p. 1168). An assertion that is well supported, via excellent individual papers (e.g., Perna et al., 2019; Purcell et al., 1998), thorough reviews (e.g., Greisberg & McKay, 2003; Kuelz et al., 2004; Olley et al., 2007) and detailed meta-analyses (e.g., Del Casale et al., 2016; Persson et al., 2021; N. Y. Shin et al., 2014; Snyder et al., 2015).

Research in this field usually infers specific executive impairments from the supposed demands of the task in question. For example, if those with OCD perform poorly on the *n*-back test (e.g., Heinzel et al., 2018; van der Wee et al., 2003), reproduction of complex visuospatial images (e.g., Rey Complex Figure Task [RCFT]; Savage et al., 1999, 2000), or complex verbal tasks (e.g., California Verbal Learning Task [CVLT]; Deckersbach et al., 2004), then this is attributed to impairments in updating, inhibition, and early encoding (i.e., a failure to organize complex information), respectively. However, some quantitative exceptions do exist. For example, Savage et al. (1999) reported that organizational strategies during the initial copy phase (i.e., early encoding) of the RCFT statistically accounted for subsequent immediate recall in those with OCD (see also Savage et al., 2000; M. S. Shin et al., 2004). Fradkin et al. (2018) also adopted a standardized approach, wherein they coded different subscores from the same tasks and measured specific aspects of flexibility (i.e., deterministic, probabilistic, and explicit shifting) in OCD.

Of specific relevance to the structure and approach of the present meta-analysis were the review paper and meta-analysis conducted by Harkin & Kessler (2011a) and Persson et al. (2021), respectively. Originally, Harkin & Kessler (2011a) elaborated on the executive-memory relationship in OCD by proposing the Executive-Function, Binding Complexity, Memory Load (EBL) Classification system. Specifically, we proposed that memory impairment occurs in those with OCD when correct and accurate performance on neuropsychological tests places sufficient demands on each of the EBL dimensions, with overall executive demands taking priority. Consequently, memory impairments in OCD occur in tasks that require high executive demands (i.e., a known area of impairment in those with OCD), inherent high binding complexity (i.e., tasks require the binding of multiple features to objects to locations; e.g., the RCFT task), and high memory load (i.e., overall complexity of stimuli to be maintained in memory; e.g., the *n*-back task at 3-back). We then (Persson et al., 2021) quantified the EBL classification system using a standardized approach similar to Fradkin et al. (2018) to understand memory impairment in OCD. In a multilevel meta-analysis, we coded individual memory tasks along the dimensions of executive function, binding complexity, and memory load as outlined in our original EBL system (Harkin & Kessler, 2011a). Despite us confirming the overall EBL system, we found that demand on executive function was the strongest predictor of memory impairment in those with OCD, as it rendered the independent contributions by binding complexity, memory load, as well as visual versus verbal task requirements nonsignificant. This latter finding was important as it helped answer a longstanding debate in the OCD-memory literature, that it is the overall executive demand of a task and not if it is visual or verbal in nature that will determine if memory impairments are present or not. For tasks with high (e.g., RCFT, *n*-back, complex story recall) versus low (e.g., neutral word recall, verbal recognition, basic Delayed-Match-to Sample [DMTS] tasks) executive demands, we observed impaired versus relatively intact memory performance in OCD, respectively. For reference, we present the EBL figure as developed by Harkin & Kessler (2011a) and Persson et al. (2021) in the online supplemental materials (S14). This we propose justifies the present finer-grained analysis of individual dimensions of executive function and their relationship to memory performance in OCD.

In sum, the previous reviews and meta-analyses highlight the following key points. (a) Executive dysfunction is an established aspect of OCD. (b) Primary executive dysfunction drives secondary memory impairment in OCD. (c) Within the OCD research, it is common to merely infer the kind of executive function impairment (e.g., organizational strategies, planning, updating, inhibition, etc.) from the supposed demands of the task in question. (d) These points highlight a gap within the meta-analytic literature, that is, the need to quantify how distinct aspects of executive function may specifically affect memory performance in OCD. This approach was further justified by Fradkin et al. (2018) who highlighted to us as OCD meta-analytic researchers the empirical importance of deriving scores from the same sessions, participants, or tasks "when reviewing neuropsychological and cognitive deficits [and that] multilevel meta-analysis … allow[s] the integration of effects of complex structures" (p. 497).

Quantification of the Top-Down and Bottom-Up Framework in OCD

We now elaborate on the proposed top-down (i.e., attentional control, maintenance and updating, planning) and bottom-up (i.e., perceptual integration, perceptual salience) framework and justify their inclusion based on their relevance to OCD symptomatology.

Top-Down Framework and OCD

From a top-down perspective and consistent with our previous conceptualizations of executive function (Harkin & Kessler, 2011a), we draw upon Wolters & Raffone's (2008) tripartite taxonomy of executive-WM function, in terms of (a) attentional control, (b) maintenance and updating, and (c) planning which they referred to as high-level integrative control.

Attentional Control. Refers to the top-down selective activation of task-relevant representations and inhibition of task-irrelevant stimuli and responses (Diamond, 2013). Top-down selective activation biases attention to specific targets externally as well as internally (Miller & Cohen, 2001). Impairment in this aspect corresponds with the obsessional focus and ruminations that those with OCD experience concerning idiographic stimuli and obsessional thinking regarding their status (Amir et al., 2008). It is the case that most individuals with OCD engage in some manner of perseveration, such as repeatedly checking stovetop burners in the fear that they have been left on (Tallis, 1995). Repeated checking has an established negative impact on the memory performance in OCD (Jaafari et al., 2013; van den Hout et al., 2019). Inhibition is defined as the ability to suppress automatic or dominant thoughts, responses, or attention to irrelevant stimuli when it is optimal to do so (Daucourt et al., 2018; Miyake et al., 2000). We further justify the inclusion of attentional control in this meta-analysis due to the established nature of inhibitory impairments (see Dupuy et al., 2013; Leopold & Backenstrass, 2015; Muller & Roberts, 2005) and associated poor memory in OCD (Harkin et al., 2011; Harkin & Kessler, 2009, 2011a, 2011b; Heinzel et al., 2018; Omori et al., 2007).

Maintenance and Updating. These are aspects of WM that explain how task-relevant information is focused on and held in an active state and when necessary, updated with more relevant information (see the unity diversity model of Executive Function by Friedman et al., 2006; Miyake et al., 2000). Wolters and Raffone (2008) proposed a top-down hierarchy in this domain. A lower level captures the maintenance of simple stimuli or features of objects, as typically employed in DMTS tasks (Harkin & Kessler, 2009). At a higher level, this involves the maintenance and flexible integration of increasingly complex relationships, operations, and rules applied to representations maintained in WM, for example, as observed in a high load condition of the *n*-back task (van der Wee et al., 2003). It is important to note that these two aspects of WM functioning are not dissociable but rather overlap at a task performance (i.e., under increasing task complexity) and a biological and computation level (O'Reilly et al., 1999). We propose that this is consistent with what we observe in OCD, with intact memory for the maintenance of simple stimuli in tasks well within capacity limits (e.g., DMTS task; Harkin & Kessler, 2009) and poor performance on tasks that require internal manipulations and complex updating of representations in WM (e.g., higher-loads within the *n*-back; van der Wee et al., 2003). Furthermore, Snyder et al. (2015) identified that updating was a vital impairment in executive function in OCD as extrapolated from performance on the *n*-back task. Thus, our aim is to investigate if it has a similarly dominant and detrimental effect on memory performance in the present meta-analysis.

Planning. In the current context, planning refers to a hierarchically organized integrative system of processing steps, driven by the executive in service of optimal memory performance (Koechlin et al., 2003). Wolters and Raffone (2008) stated that planning is responsible for a "high degree of information integration (e.g., planning and problem-solving)" (p. 7) and the selection of task-relevant representations "according to events that previously occurred or to ongoing internal goals" (Koechlin et al., 2003, p. 1,181). It is common to observe planning impairments in OCD (e.g., Hybel et al., 2017; Leopold & Backenstrass, 2015; Snyder et al., 2015). Specifically, Mataix-Cols et al. (2003) reported that deficits in the reconstruction from memory of a complex visual image (e.g., RCFT) were potentially mediated by deficits in a cognitive organization and planning (see Sherman et al., 2006; M. S. Shin et al., 2004). We also draw support for the importance of planning in OCD as it is identified as a potential cognitive endophenotype; i.e., planning deficits are similarly present in those with OCD and unaffected first-degree relatives (Bey et al., 2018). To date, no reviews have estimated the predictive power of planning in isolation and relative to other aspects of executive control.

Bottom-Up Framework and OCD

Bottom-up processing explains how a salient external stimulus (e.g., loud noise, your name, objects related to idiographic OC symptoms) grabs attention intentionally or unintentionally (Diamond, 2013). Specifically, such stimuli automatically alert, orient, and require integration and encoding of stimulus features across and within individual sensory modalities (Desimone & Duncan, 1995) and WM (Awh et al., 2006). Thus, in the words of Awh et al. (2006), the quality of these early perceptual inputs across these sensory modalities acts as a potential gatekeeper to WM (p. 202). Consequently, interference at this early stage necessarily hampers the quality, veridicality, and durability of the inputs that are subsequently maintained in WM (Jolicoeur, 1999).

Some research has indicated issues in early perceptual processing in OCD. For example, those with OCD had less confidence in their perceptual (i.e., bottom-up) capacities (Hermans et al., 2008). In a nicely nuanced meta-analysis, Strauss et al. (2020) reported that those with OCD checked more in tasks that tapped into perceptual processing but not reasoning. It is important to note that none of these papers, and no others to our knowledge, quantified the impact of bottom-up processes on memory performance *per se*. To distinguish these from active top-down operations, we look at bottom-up processing from the perspective of the content and nature of the stimuli, in terms of their perceptual integration and perceptual salience, respectively.

Perceptual Integration. Refers to the ability to combine fragmentary inputs from different sensory modalities into coherent and perceptually organized objects (Fahrenfort et al., 2017). Above, we highlighted those impairments in integration at a top-down binding and planning level that contribute to memory impairments in OCD (Mataix-Cols et al., 2003). In contrast, limited and sometimes equivocal research exists for perceptual integration impairments in OCD, which leaves us in a position of tentative supposition and extrapolation.

For example, Harting & Markowitsch (1997) suggested that impairments in the construct of complex visual stimuli (e.g., RCFT) in OCD are attributable to issues of Gestalt perception. Contrastingly, Moritz & Wendt (2006) reported no deficits in early perceptual encoding for local elements in those with OCD. Fergus & Carleton (2016) reported that a key symptom in OCD—that is, intolerance of uncertainty—is associated with hyperactive bottom-up attentional processing. Individuals who experience greater intolerance of uncertainty are more likely to look for and perhaps even find uncertainty in simple visual stimuli. Shahar et al. (2017) suggested that those with OCD suffer from perceptual deficits in their ability to classify and identify stimuli, which may explain the overly cautious and perseverative behaviors common to OCD. Lastly, and related to the above finding, in healthy controls, perseverative and prolonged staring—a common symptom in OCD—is associated with reduced trust in perception, likely for specific sensory attributes; for example, color and detail (van den Hout et al., 2009). So, although we can see some evidence for qualitative impairments in bottom-up perceptual integration, a systematic quantification regarding their impact on memory performance in OCD is lacking.

Perceptual Salience. Denotes the extent that we are drawn (or not) to the inherent properties of stimuli, for example, their prominence, contrast to a background or their ability to evoke strong emotions across a range of modalities (e.g., bright colors, complex or moving stimuli or acute sounds and feedback; Corbetta & Shulman, 2002). Neuropsychological research indicated that those with OCD show impairments in their salience networks (bottom-up) in addition to their executive networks (top-down, as described above), which may explain why they are poor at disengaging from externally salient stimuli and engaging in goal-directed behaviors, respectively (Chen et al., 2018; Gürsel et al., 2018). Foa et al. (1997) also noted that those with checking-based OCD showed evidence of perceptual distractibility; that is, they rated task-irrelevant background noise louder than controls. A simple bottom-up bias to salient and task-irrelevant stimuli (e.g., colorful, moving, or noisy tasks) may interfere with the veridicality of early inputs that reach WM in the service of task demands (Awh et al., 2006; Jolicoeur, 1999). However, despite the logic of this supposition, no research to date has quantified the impact of stimulus salience, from a bottom-up processing perspective, upon memory performance in OCD.

The Present Meta-Analysis

The present multilevel meta-analysis aims to determine the contribution of top-down (attentional control, maintenance and updating, planning) and bottom-up (perceptual integration, perceptual salience) processes on memory performance in OCD (Fradkin et al., 2018). Through exploratory analyses, we will also quantify these factors on the memory performance of those with subclinical and clinical OCD separately. Lastly, in accord with previous research (e.g., Juni et al., 2001; Moher et al., 1999), we also examined whether methodological quality contributed to any of the effect sizes (Leopold & Backenstrass, 2015; Persson et al., 2021).

Method

Selection of Studies

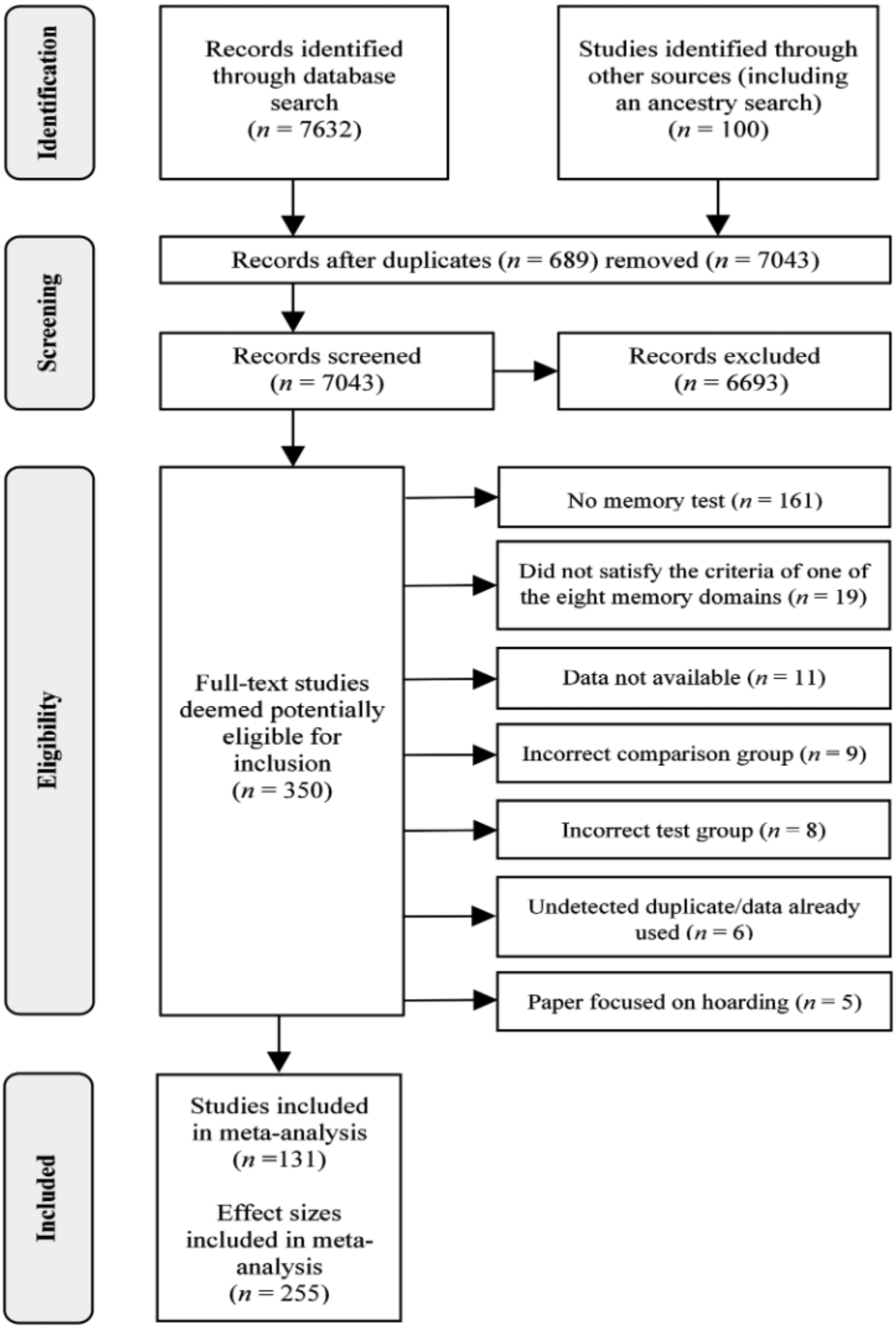
We included peer-reviewed studies published in English that compared memory performance on at least one memory task (i.e., visual, verbal, or a combination of the two) between adults with OCD or OCD-type traits (e.g., checking) and healthy controls. This included subclinical participants who had elevated scores on standardized self-report questionnaires of OCD symptoms, yet their frequency and severity of symptoms fell short of a clinical diagnosis for OCD (e.g., Mataix-Cols et al., 2000). The search terms used to access literature were "(wash* OR check* OR hoard* OR obsessive-compulsive* OR OCD OR clean*) AND (executive OR bind* OR load* OR visual OR verbal) AND (memory)." Previous literature informed the selection of the keywords, for example, Leopold and Backenstrass (2015) and Persson et al. (2021). In January 2021, the completed database search identified 7,632 studies and 100 from additional sources (including an ancestry search). A full-text examination of 350 articles identified 131 suitable for the final review (see S13 in the online supplemental materials for comparison to Persson et al., 2021). Figure 1 provides an overview of the PRISMA flowchart with full methodological and descriptive details provided in S2–S7 in the online supplemental materials.

Standardization of the Top-Down and Bottom-Up Framework

We standardized each task along each dimension of attentional control, maintenance and updating, planning, perceptual integration, and perceptual salience. We created a system that was simple (i.e., aiding replication) and produced meaningful ordinal differences for each dimension. For example, when a given task received a high score

Figure 1

PRISMA Flow Chart Detailing the Database Searches, Number of Abstracts Screened, Basic Exclusion Criteria and Number, Final Studies Included, and Number of Effect Sizes Calculated



Note. Regarding screening, the software used (Rayyan; Ouzzani 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); nonhuman investigations (e.g., rats); and paper was a meta-analysis and contained no new data. PRISMA = Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

for attentional control, it differed in obvious and pragmatic ways from one that scored lower on this dimension. Therefore, for each dimension we defined its primary characteristics and how we ranked each task in terms of high (3), medium (2), or low (1) demand (see S8 in the online supplemental materials).

Results

Analysis Strategy

Cohen's *d* was utilized as a measure of the effect size of the difference in performance on each of the memory tasks between OCD participants and healthy controls, with a positive effect size indicating a memory deficit among participants with OCD as compared to control participants. For the overall mean effects of the meta-analysis and mean effects of categorical moderators, we report Cohen's *d*, and for mean effects within the continuous moderator analyses, we report standardized betas (β) (see S9 in the online supplemental materials for details on analysis strategy). The analyses for the top-down and bottom-up frameworks use visual/verbal as a single predictor, and we also provide an illustration of mean effects for visual and verbal using the dummy coded variables provided in Table 1.

Main and Heterogeneity Analyses

Across 255 effect sizes from 131 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 [0.43, 0.56], $p < .001$. The second step of the analysis estimated the variance distribution across the three levels. Based on formulas by Cheung (2014), the total variance distribution was as follows: Level 1: 33.44%; Level 2: 32.56%; Level 3: 33.00%. Assink & Wibbelink (2016) recommend conducting moderation analyses if less than 75% of the variance is attributed to Level 1.

Top-Down Moderator Analyses

For the moderation analysis for the top-down framework, we entered attentional control, maintenance and updating, and planning simultaneously into the model together with whether the task was visual or verbal in nature (Table 1), alongside methodological quality (see S11 in the online supplemental materials for the approach to moderator analyses). The model was significant $F(5, 249) = 16.63$, $p < .001$. In this model, the only significant predictor was maintenance and updating: $\beta = .29$, $SE = .06$, $p < .001$. Therefore, it is the extent that tasks require maintenance and updating that is the main predictor of differences in the memory performance of those with OCD and controls, when considered within the framework of top-down functions. Moreover, whether the task is visual or verbal was not significant in this context: $\beta = -0.07$, $SE = .0.06$, $p = .24$.

Bottom-Up Moderator Analyses

The bottom-up (perceptual integration and perceptual salience) model was significant $F(5, 250) = 18.10$, $p < .001$. In this model, the only significant predictor was perceptual integration: $\beta = .24$, $SE = .07$, $p < .001$. Therefore, it is the demand that tasks place on perceptual integration that is the main predictor of differences in the memory performance of those with OCD and controls, in the context of the bottom-up framework. Again, whether the task is visual or verbal in nature was not significant: $\beta = -0.002$, $SE = .0.06$, $p = .97$. Figure 2 illustrates the significant moderation effects for maintenance and updating (top-down; left panel), and perceptual integration (bottom-up; right panel).

Visual and Verbal Moderator Analyses

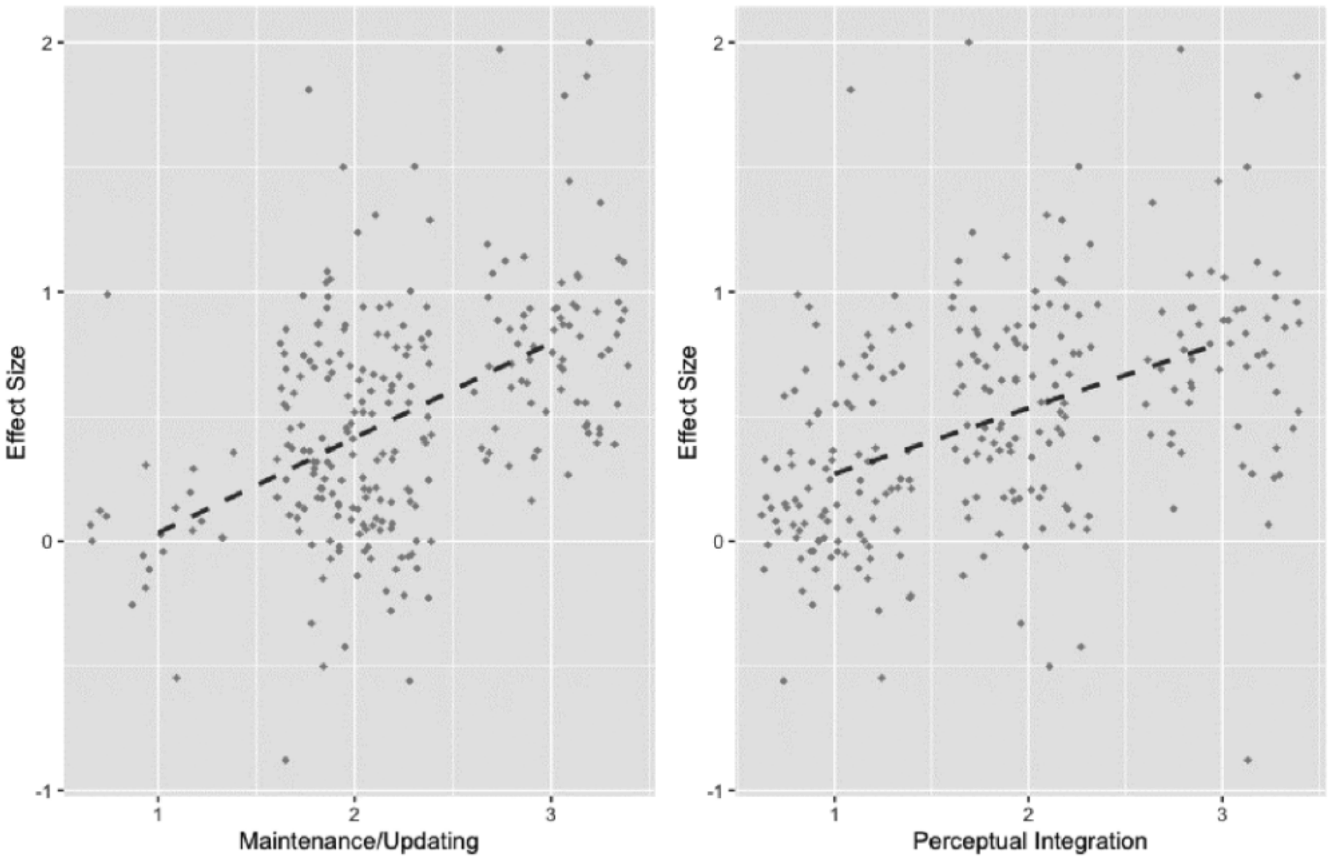
The analysis of the moderating influence of whether the task was visual or verbal in nature showed that visual tasks produced the greatest

Table 1
Main and Moderator Analyses

Variable	*k*	*d* (*SE*)	*p*	C−, C+	*Q* (*p*)
Main analysis	255	0.50 (0.03)	<.001	0.43, 0.56	704.40 (<.001)
Variable	***k***	**β (*SE*)**	***p***	**C−, C+**	***Q* (*p*)**
		Top-down			
Attentional control	255	0.10 (0.05)	.051	−0.001, 0.21	535.73 (<.001)
Maintenance and updating	255	0.29 (0.06)	<.001	0.18, 0.40	535.73 (<.001)
Planning	255	−0.02 (0.05)	.70	−0.12, −0.08	535.73 (<.001)
Visual/verbal[a]	255	−0.07 (0.06)	.24	−0.18, 0.05	535.73 (<.001)
		Bottom-up			
Perceptual integration	255	0.24 (0.07)	<.001	0.10, 0.37	554.92 (<.001)
Perceptual salience	255	0.02 (0.06)	.76	−0.10, 0.14	554.92 (<.001)
Visual/verbal[b]	255	−0.002 (0.06)	.97	−0.12, 0.12	554.92 (<.001)
Variable	***k***	***d* (*SE*)**	***p***	**C−, C+**	***Q* (*p*)**
		Type of task			
Visual	255	0.63 (0.05)	<.001	0.56, 0.71	636.01 (<.001)
Verbal	255	0.37 (0.05)	<.001	0.29, 0.45	636.03 (<.001)

Note. k = total number of studies included for each task. d (*SE*) = effect size in Cohen *D* (*SE*); β = *standardized* β (*SE*). p = significance. C−, C+ = confidence intervals. $Q(p)$ = Q statistic.
[a] When measured in isolation outside of the top-down and bottom-up framework. [b] The differing results for visual/verbal are due to this variable being entered into two different models (top-down vs. bottom-up).

Figure 2
Framework Moderation Plots for Significant Moderators



memory deficiency in those with OCD, as compared to healthy controls. Specifically, the overall mean effects for visual and verbal tasks were $d = 0.63$, $SE = 0.05$, 95% CI [0.54, 0.71], $p < .001$, and $d = 0.37$, $SE = 0.05$, [0.29, 0.45], $p < .001$, respectively. However, we note that when these effects are examined in the context of top-down and bottom-up factors (as outlined above), they are no longer significant.

Exploratory Analyses: Clinical and Subclinical OCD Comparison

Unsurprisingly, the memory deficit for the clinical OCD group was greater ($d = 0.51$, $SE = 0.04$, 95% CI = [0.45, 0.58], $p < .001$), as compared to the nonclinical group ($d = 0.30$, $SE = 0.09$, [0.10, 0.50], $p = .02$. The moderation model results for the top-down model for the clinical OCD group, $F(5, 230) = 16.47$, $p < .001$, largely mirrored the results for the overall sample, where maintenance and updating remained the only significant predictor in this framework, $\beta = .27$, $SE = .06$, [0.16, 0.39], $p < .001$, when controlling for multiple comparisons (using the Bonferroni correction). Similarly, the bottom-up framework model was also significant, $F(4, 231) = 19.12$, $p < .001$, and perceptual integration remained the only significant predictor: $\beta = .24$, $SE = .07$, [0.10, 0.38], $p < .001$.

Interestingly for the subclinical OCD sample, neither the moderation analyses for the top-down, $F(5, 13) = 1.12$, $p = .40$, nor the bottom-up, $F(4, 14) = 1.14$, $p = .96$, framework was significant. These results indicate that top-down and bottom-up processes may differently affect the memory performance of those with subclinical compared to clinical OCD. Specifically, Figure 3 illustrates the moderation effects for maintenance and updating (top-down; left panel) and perceptual integration (bottom-up; right panel) for memory performance of the subclinical (dashed line) compared to the clinical (solid line) OCD group. These results should, however, be interpreted with caution, as there were considerably more effect sizes for the clinical OCD group ($k = 236$), as compared to the subclinical OCD group ($k = 19$). Here, we are *not* stating those with subclinical OCD are not a valid analog for clinical OCD nor that they do not have impairments in executive function or memory, only that the present model did not significantly explain memory impairments in those with subclinical OCD.

Subgroup, Study Quality, and Publication Bias Analyses

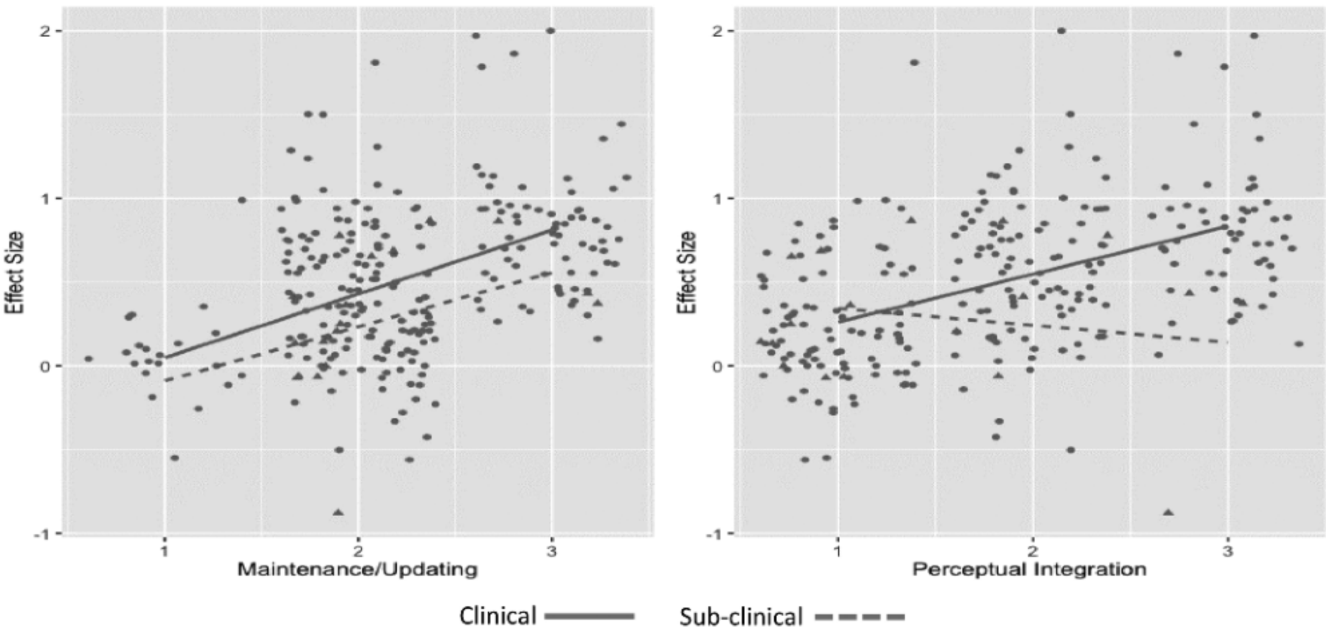
Figure 4 is a descriptive illustration of effects across the different task categories. As per Harrer et al. (2019) subgroup estimates were obtained through individual moderation analyses, using each task category as the moderator, and it does as such not reflect any overall moderation effects. Study quality and publication bias did not contribute to observed effect sizes (S12 in the online supplemental materials).

Discussion

Executive function and memory performance are a common focus in the OCD literature (e.g., Olley et al., 2007; Persson et

Figure 3

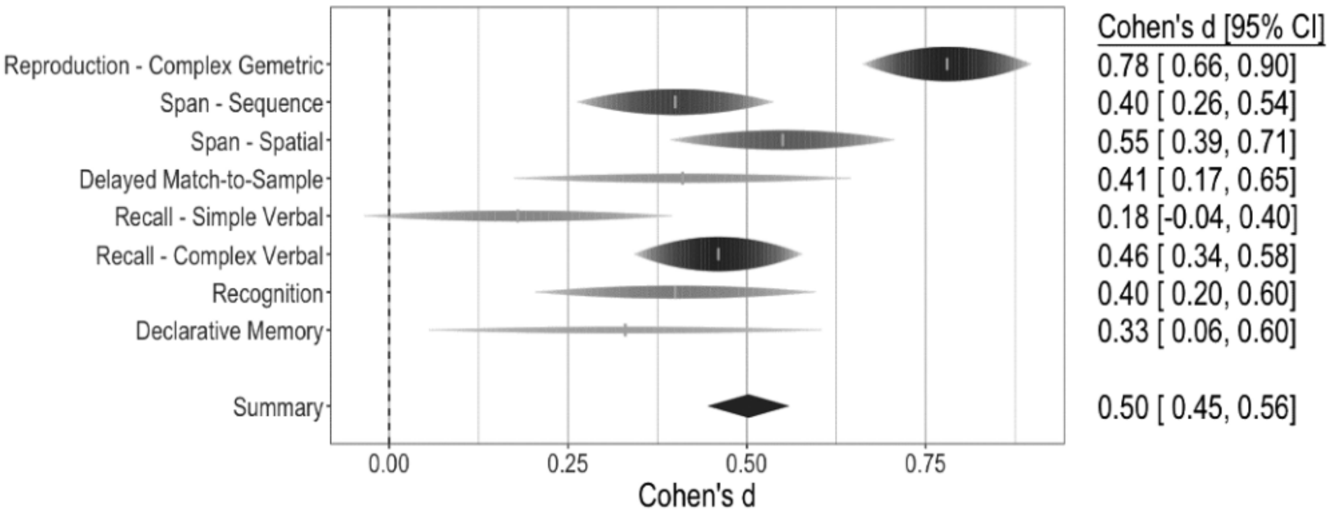
Framework Moderation Plots for Clinical and Subclinical Groups for Maintenance and Updating (Top-Down) and Perceptual Integration (Bottom-Up)



al., 2021; Snyder et al., 2015). However, the contributions of specific aspects of executive control relative to each other toward the memory performance of those with OCD have remained elusive (Bedard et al., 2009). We propose that this is due to a general failure to classify memory tasks according to reliable criteria. In turn, this makes it difficult to determine the relative contributions of specific facets of executive function to memory performance in OCD (Persson et al., 2021; N. Y. Shin et al., 2014). Therefore, we drew upon the method of Fradkin et al. (2018) and extended our previous meta-analysis where we identified executive control as the primary driver of memory impairment in OCD (Persson et al., 2021). Specifically, we provided a finer-grained analysis in terms of a top-down (attentional control, maintenance and updating, planning) and bottom-up (perceptual integration, perceptual salience) framework and quantified its impact on memory performance in OCD.

Figure 4

Subgroup Forest Plot Effect Sizes for Each Memory Domain



Note. A compact shape in darker shade visualizes a larger sample size and narrower confidence intervals. Conversely, elongated shapes in lighter shade visualize smaller sample sizes and wider confidence intervals. The diamond shape at the bottom indicates the overall effect size for the full sample, with estimated confidence intervals.

Significance of Model

We propose that our current top-down and bottom-up frameworks are significant when applied to OCD-memory research, especially when considered in the context of how they complement past research on this topic. First, 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; Persson et al., 2021; N. Y. Shin et al., 2014; Snyder et al., 2015). Second, consistent with pertinent literature (Abramovitch et al., 2013; Abramovitch & Cooperman, 2015; Muller & Roberts, 2005; Olley et al., 2007), we observed that OCD participants had greater impairment in visual ($d = 0.63$) compared to verbal tasks ($d = 0.37$). We also found similar effect sizes to extant research for specific memory domains; for example, the reproduction of complex visual ($d = 0.78$) and verbal (0.46) information, with comparatively minor impairments for the recall of simple verbal information ($d = 0.18$) (N. Y. Shin et al., 2014; Snyder et al., 2015). Therefore, the comparison with past literature combined with our relatively large sample size (255 effect sizes) gives us confidence that our results are not attributable to small sample sizes, spurious coding, or issues of study inclusion.

Top-Down and Bottom-Up Framework

Our top-down model predicted memory performance in OCD, where we saw that as top-down demand generally increased, those with OCD had poor memory relative to controls. Within the top-down model, only maintenance and updating (in comparison to attentional control and planning) predicted memory performance in OCD. Therefore, within the context of top-down functions, whether a task is high in maintenance and updating is the main influencing factor in the memory difference between those with OCD and controls.

Our bottom-up model also predicted memory performance in OCD, as we saw that as bottom-up demand generally increases, those with OCD had poor memory relative to controls. Within the bottom-up model, only perceptual integration (vs. perceptual salience) predicted memory performance in OCD. Importantly, analyzing the dimensions of the top-down and bottom-up framework resulted in a nonsignificant contribution of the visual-verbal distinction, a finding that is consistent with our previous research (Persson et al., 2021), where executive function similarly resulted in nonsignificant contributions of whether a task was visual or verbal in nature.

In keeping with our previous research (Harkin & Kessler, 2011a; Persson et al., 2021), perceptual integration as well as maintenance and updating are well aligned with the Executive-, Binding-, Load-(EBL) classification system of OCD deficits (Harkin & Kessler, 2011a), where the Binding (B) and Load (L) dimensions are obliquely aligned with the dominant Executive (E) dimension, as they partially depend on executive dysfunction to result in OCD deficits. The dimensional assumptions of the EBL framework were confirmed by the Persson et al. (2021) meta-analysis and dovetail nicely with the importance of perceptual integration and maintenance and updating costs reported here. Specifically, both appear to relate to stimulus complexity potentially affecting binding and load demands as well as increasing maintenance and updating costs and fragility of the ensuing complex representations in memory.

Clinical Status, Top-Down and Bottom-Up Framework, and Memory Performance

Our exploratory analyses found that memory impairment was greater for the clinical ($d = 0.51$) compared to the subclinical group ($d = 0.30$; Figure 3). Second, for the clinical group, the pattern for the top-down and bottom-up dimensions mirrored that of the overall sample. Maintenance and updating (top-down) and perceptual integration (bottom-up) were the only significant predictors of poor memory performance in this group. For the subclinical group, neither the top-down nor the bottom-up frameworks predicted their memory performance. Thus, despite us reporting a memory deficit for both the clinical and subclinical group as compared to healthy controls, our top-down (i.e., maintenance and updating) and bottom-up (i.e., perceptual integration) frameworks only predicted a detrimental impact on the memory performance of those with clinical not subclinical OCD. We propose that at least for the top-down and bottom-up framework applied here, those with subclinical symptoms may not always be an appropriate analog to those with clinical obsessive-compulsive symptoms (Mataix-Cols et al., 1997). However, this conclusion remains tentative and should be interpreted with caution, given that these analyses were exploratory, and that the subclinical group had a low number ($n = 19$) of effect sizes.

Faulty Sensory and WM Gating: A Unified Mechanism of Memory Performance in OCD

To explain the pattern of memory impairment of those with clinical OCD in the context of our bottom-up and top-down framework, we draw upon research on faulty gating mechanisms within early sensory processing (Podoly & Ben-Sasson, 2020; Prado et al., 2008) and WM (Nyberg & Eriksson, 2015; Rac-Lubashevsky et al., 2017). We adopt the view of Awh et al. (2006) where (in)effective perceptual encoding acts as a gatekeeper for what passes into WM and provide an overview in Figure 5.

Sensory Gating in Clinical OCD. Sensory gating describes the mechanism of filtering task-irrelevant stimuli from those available in the external environment (Cromwell et al., 2008), a process affected by factors such as anxiety and selective attention (Wilson, 2008). A deficit in sensory gating is present in several mental illnesses and underlies associated disturbances in cognition (van den Buuse, 2007), with impairments in sensory gating of early perceptual stimuli present in OCD (Hoenig et al., 2005). For example, Podoly & Ben-Sasson (2020) proposed sensory over-responsivity (SOR) to explain sensory symptoms of OCD, where those with OCD are slow to habituate to sensory stimuli and pay unnecessary and obsessive attention to details of a given stimulus (Prado et al., 2008). They reported that those with more severe OC symptoms had greater SOR (i.e., slower sensory habituation: prolonged attention to stimulus features beyond task requirements) when compared to those with lower OC scores.

Deficits in sensory function are consistent with empirical findings on: (a) focused attention at a specific point of an image reducing the integration of the whole image; (b) early encoding and WM impairments observed in OCD; and (c) the development and maintenance of symptoms in OCD. First, it is observed that bottom-up attention influences spatial resolution (i.e., the amount of spatial detail in an observation; Carrasco & Barbot, 2014) at an attended location

Figure 5

Overview of Present Meta-Analysis, Faulty Cognitive Mechanisms, Expression in OC Symptoms, and Interventions

Focus of Present Meta-Analysis	Bottom-Up	Top-Down	Memory Performance
Identified Deficit in Present Meta-Analysis	*Perceptual Integration* Encoding of individual features vs. whole	*Maintenance* Poor organization of complex representations *Updating* Individual items overload working memory &/or deficits at high loads	Less accurate maintenance of complex information in working memory Inefficient updating of working memory as distinct information progressively increases in load
Explanatory Faulty Cognitive Mechanism	*Sensory Gating* Less inhibition of irrelevant features, abnormal sensitivity to sensory stimuli and deficit in sensory habituation	*Working Memory Gating* Excessive 'Opening' & 'Closing' of gates, destabilisation of representations in working memory	Memory Impairment
Expression in Obsessive Compulsive Symptoms	Obsessional slowness, uncertainty, not quite right feelings, awareness of ambiguity, stimulus perseveration	Obsession on details vs. whole stimulus, prolonged maintenance and/or chronic updating of stimulus features, cognitive fatigue	Poor memory, less confidence in status of original stimulus and/or contents of memory, further checking, anxiety
Intervention Targets	Label task relevant sensory features at encoding	Target selective gating strategies: i.e., contextual/cue driven executive control to override habitual, chronic & faulty updating seen in OCD	

Note. The arrows in this figure indicate a proposed relationship and direction of possible causality within and between each of the four main sections. (Panel a) *Identified Deficits in Present Meta-Analysis*: The arrow indicates how impairments in perceptual integration influence how information is maintained and updated in WM, and then how these influence overall memory performance in those with OCD. (Panel b) *Exploratory Faulty Cognitive Mechanism* and *Expression in OC Symptoms*: The arrows indicate the direction of our proposed faulty gating mechanisms (i.e., sensory and WM) and their expression in OCD symptoms (e.g., uncertainty and obsession with details, respectively). (Panel c) *Intervention Targets*: The arrow in this instance indicates how the proposed intervention will potentially counter issues in OC symptoms and the proposed faulty gating mechanisms. OC = obsessive-compulsive; WM = working memory; OCD = obsessive-compulsive disorder.

(Banerjee et al., 2017). For example, for tasks that require the integration of information at and around a region of attentional focus, the increase in spatial resolution at this central location reduces the integration of information around it (Banerjee et al., 2017; Yeshurun & Carrasco, 2000). In turn, this is consistent with research that shows those with OCD suffer deficits in perceptual integration during encoding (uncertainty, Fergus & Carleton, 2016; Gestalt perception, Harting & Markowitsch, 1997; identification and classification, Shahar et al., 2017), which then influences the memory performance of those with OCD. For example, when those with OCD copy complex visuospatial images (e.g., RCFT), they tend to overly attend to specific details of an image, to the detriment of its overall perceptual integration and subsequent recall. We propose that this contrasts with control participants who distribute attention (i.e., spatial resolution) evenly across the image as they start to copy the larger shapes followed by finer details, which results in relatively more accurate memory performance (Boldrini et al., 2005). Overall, this finding is consistent with other meta-analyses (Leopold & Backenstrass, 2015; N. Y. Shin et al., 2014; Snyder et al., 2015) as well as the current review, where an increasing demand on perceptual integration was associated with poor memory performance in those with OCD.

Working Memory Gating in Clinical OCD. Theories of maintenance and updating have proposed that efficient WM depends on a gating mechanism as a solution to controlling changing inputs and task demands (Chatham & Badre, 2015; Nyberg & Eriksson, 2015; Rac-Lubashevsky et al., 2017). A *closed* gate promotes the maintenance of relevant information within WM while simultaneously keeping irrelevant information out and protecting capacity limits (Cowan, 2001). In contrast, an *open* gate promotes updating via the removal, replacement, or addition of new information to accommodate evolving task demands (Kessler, 2017). Within OCD, we suggest that overloading and overuse of this "gating" mechanism may explain the pattern of memory impairments observed in our meta-analysis.

We propose that deficits in maintenance and updating are unlikely due to capacity, as a consistent finding in the literature is that it is intact in OCD (Leopold & Backenstrass, 2015; N. Y. Shin et al., 2014; Snyder et al., 2015). This assertion is in accord with the proposal that the maintenance of information in WM is an active process (Nader, 2015), which explains the common observation of memory impairments in OCD for tasks high in their organizational demands (e.g., CVLT, Deckersbach et al., 2004; e.g., RCFT, Savage et al., 1999). Research on updating and memory impairments in OCD further supports this assertion (Persson et al., 2021; Snyder et al., 2015; e.g., van der Wee et al., 2007).

In Figure 5, we outline a potential interrelationship of faulty gating mechanisms at a sensory (bottom-up) and WM (top-down) level to explain common patterns of memory impairment observed in OCD. As those with OCD suffer deficits in early perceptual integration, they tend to focus on and encode individual pieces of information over the whole. In accord with our data pattern, this occurs above and beyond whether the task is visual or verbal nature and appears to be due to the overall complexity of the stimuli used in a given memory task (Persson et al., 2021). As a result, a series of independent and potentially disparate items enter WM (Awh et al., 2006), which then promotes the excessive opening and closing of the gate to allow the updating and maintenance of this information in WM. What we are potentially observing in OCD is a shift from a global gating mechanism to one that is highly selective, stimulus-driven, and retroactive in nature (Chatham & Badre, 2015; Rac-Lubashevsky et al., 2017). Overloading such a gating mechanism likely destabilizes the veridicality of the information maintained and updated within WM (Dipoppa et al., 2016). This assertion is consistent with the observation that those with OCD suffer impairments in tasks that require explicit updating (e.g., span sequence, *n*-back) in the service of accurate WM performance (van der Wee et al., 2007).

We propose that our gating explanation shines an informative light on the clinical versus subclinical pattern we observed across the bottom-up and top-down frameworks, but must be interpreted with care, given the low number of effect sizes ($n = 19$) in the subclinical group, and the exploratory nature of these analyses. Specifically, despite the observation that those with clinical OCD had more acute impairments in memory compared to those with subclinical OCD ($d = 0.51$ vs. 0.30, respectively), it was only for the clinical group that perceptual integration (bottom-up) and maintenance and updating (top-down) was associated with poor memory performance. Therefore, although memory is impaired generally in OCD (across subclinical and clinical groups), these two dimensions are associated with an exacerbation in mnestic deficits at a clinical level. This suggestion is consistent with the symptoms of those with OCD, in terms of the range of impairments and issues they have concerning stimuli specific to their symptoms (Amir et al., 2008), for example (as shown in Figure 5), poor memory (Harkin et al., 2011), lack of confidence (Tolin et al., 2001), a desire to physically check and recheck (van den Hout & Kindt, 2003b), awareness of ambiguity (Harkin & Mayes, 2008), cognitive fatigue (Pasquini et al., 2015), and anxiety and avoidance (Abramowitz, 2006).

Lastly, our results and gating explanations offer a unique avenue of future research with respect to key OCD literature that shows checking causes doubt in memory processes (van den Hout et al., 2019). Specifically, our research perhaps indicates that those with OCD hold preexisting top-down and bottom-up context-independent impairments that potentially prime them to seek out ambiguity and uncertainty in their environment (Harkin & Mayes, 2008), and potentially even more so in the presence of threat-related stimuli (Salkovskis, 1999). For example, research indicates a relationship between uncertainty and reduced visuospatial memory performance in those with OCD (Lambrecq et al., 2014), and intolerance of uncertainty with the frequency of compulsive checking (Lind & Boschen, 2009). We also note similarities between our present theory to research conducted by Lazarov et al. (2010). Specifically, they reported that those with OCD suffer an inability to correctly base decisions on their internal states (akin to context-independent failures in top-down and bottom-up processing), which then potentially drives them to use and check external states to reduce doubt and uncertainty from their thoughts and behaviors. Therefore, we advise future research to investigate if aberrant top-down and bottom-up processes act as potential primers for the development of symptoms like compulsive checking or a preference for external states, and if targeting the gating mechanisms that we outline will improve key therapeutic factors in OCD.

Clinical Implications

We now aim to address a point raised by Ouimet et al. (2019) who highlighted the need to focus "on novel domains and aspects of cognition that people struggling with OCD complain of during assessment and therapy sessions" (p. 25). The first line treatment of OCD is cognitive behavior therapy (CBT) with exposure and response prevention (ERP) either in isolation or in combination with selective serotonin reuptake inhibitors (SSRIs, clomipramine; Fineberg et al., 2020). CBT is generally known to target top-down control, whereas pharmacological interventions may act more on bottom-up processes (Godlewska & Harmer, 2021). For example, Kuelz et al. (2006) reported that after CBT, those OCD participants identified as major responders improved to a greater extent than minor responders on the immediate and delayed aspects of the RCFT. We propose that in our framework, RCFT performance is highly dependent on the top-down processes of maintenance and updating (Voderholzer et al., 2013). Whereas, from a bottom-up perspective, a possible suggestion is that pharmacological interventions potentially reduce interference from bottom-up effects (e.g., perceptual integration) which may increase patients' responsivity to the top-down effects of treatments such as CBT. (Roiser et al., 2012). Therefore, we advise future research to identify the individual and combined impact of CBT and pharmacological interventions on top-down and bottom-up processes, in addition to quantifying the relationship between these interventions and processes on the neuropsychological performance (central executive, memory performance) and treatment outcomes (general effectiveness, persistence, subsymptoms) in those with OCD.

Limitations and Future Research

Even though we support our top-down and bottom-up framework and respective dimensions via relevant theoretical (Wolters & Raffone, 2008) and established executive deficits in OCD (Olley et al., 2007; N. Y. Shin et al., 2014; Snyder et al., 2015), we are aware that memory impairments in OCD are not limited to these factors. We advise future research to adopt a multidimensional approach to categorize different cognitive factors such as repetitive checking (e.g., van den Hout & Kindt, 2003b), ecological validity (e.g., Harkin et al., 2011), subsymptoms (e.g., checking, washing;

Thordarson et al., 2004), and comorbidities (e.g., depression and anxiety; Moore & Howell, 2017) and quantify their impact on memory performance in OCD.

Second, an issue pertains to how this meta-analysis and others choose to categorize a given task (see Abramovitch et al., 2015). For example, Abramovitch et al. (2013) defined digit span as a measure of WM, N. Y. Shin et al. (2014) categorized it as a measure of attention, whereas we placed it within the span-sequence domain. Here, we are not implying that either of these categorizations is incorrect as this task and others likely include all these components. Rather, we follow the recommendations of an excellent review of methodological issues in OCD research by Abramovitch et al. (2015), which identified the need for "researchers [in the OCD field] to make an effort to carefully define the construct they wish to investigate, leading to selection of more specific and reliable measures" (p. 117). Also relevant to the present findings, they identified that OC subsymptoms (i.e., checkers vs. washers) clinical correlates, medication status, and age of onset are likely to influence neuropsychological performance in OCD. However, we did not investigate these and other factors in the present meta-analysis despite their likely influence on effect sizes. We propose that future research could categorize factors such as depressive symptoms as present or absent, in terms of severity (i.e., low, medium, high), or alongside other comorbidities. This is important as the severity of depression in those with OCD is negatively associated with aspects of their executive function and memory performance (Bedard et al., 2009). Also, medication status has an interesting relationship with neuropsychological performance in those with OCD. For example, Abramovitch et al. (2013) reported that OCD patients' central executive performance was impaired when they were taking neuroleptics; future research could categorize those with OCD by their medication status (i.e., taking or not), type of medication (e.g., SSRIs, neuroleptics), dosages (i.e., low, medium, high), and time-period of consumption and then quantify their impact on neuropsychological performance (e.g., central executive, memory).

Few studies in the current sample included ecologically valid (i.e., threat-related; context-dependent) stimuli in the context of memory performance in OCD. Therefore, although we can comment on how content-independent biases influence memory performance, we are unable to fully comment on how context-dependent biases noted by influential researchers such as Salkovskis (1999) and memory biases in favor of threat-related stimuli in OCD influenced our current findings (Radomsky & Rachman, 2004). As such, we advise future research to more readily employ OCD-relevant stimuli (Harkin et al., 2011; Tolin et al., 2001) and quantify their effect on memory performance in those with OCD.

Lastly, it is important to note that our top-down versus bottom-up conceptualization and coding potentially gives the impression that we view these as entirely separate and dissociable processes. This is not the case as we appreciate that given cognitive processes, task demands, and stimulus features likely exist along a top-down bottom-up continuum, with some easier to position on that continuum compared to others (McMains & Kastner, 2011). For example, meta-cognition versus a loud unexpected sound will initially place demands on top-down and bottom-up processing, respectively. However, even for a loud unexpected noise, after initially triggering bottom-up processes, very quickly top-down attentional process will increasingly come into operation. Thus, we view bottom-up and top-down processes in an integrative manner, especially with respect to memory performance in OCD, and as we outline in Figure 5 and associated discussions.

Conclusion

The present meta-analysis indicates that our top-down and bottom-up framework can explain the pattern of deficient memory performance of those with OCD. Specifically, we report that maintenance and updating (top-down) and perceptual integration (bottom-up) were the strongest predictors of memory impairment in OCD above and beyond whether the visual versus verbal task distinction. Exploratory analyses indicated that these factors predicted the memory performance of those with clinical OCD more reliably than of those with only a subclinical expression, although sample sizes were highly skewed in favor of clinical studies. In Figure 5, we outline a sequential relationship between faulty cognitive mechanisms in sensory and WM gating, their expression in OC symptoms, and the identification of viable interventions to these underlying cognitive processes.

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Studies included in the meta-analysis are indicated below with an asterisk.

The full list of studies included in the meta-analysis is provided in the online supplemental materials (S1).

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