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The Writing Brain: Writing as an Exercise of Functional Network Optimization to Facilitate Psychologically Healing Effects

Isabelle Antolin

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The Writing Brain: Writing as an Exercise of Functional Network Optimization to Facilitate Psychologically Healing Effects

A Thesis Presented

by

Isabelle Antolin

To the Keck Science Department

of

Claremont McKenna, Scripps, and Pitzer Colleges

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Abstract

James Baldwin wrote, “When you’re writing, you’re trying to find out something which you don’t know” (as cited in Plimpton 1989). Writers, like James Baldwin, have for a long time acknowledged that writing has some psychological effect. However, the neural basis of this effect has yet to be understood. Neuroimaging studies have examined writing as a creative process, identifying a predominantly left fronto-parieto-temporal network activation during writing tasks (including brainstorming, drafting, and revising). Importantly, one study examining poetry composition found that a generative phase of writing was associated with a significant anti-correlative activation pattern between the dorsal attention network (DAN) and the default mode network (DMN). Additionally, during revision this anti-correlation was attenuated, indicating that different writing tasks require a modulation of the top-down attentional control provided by the DAN. To unify these neuroimaging findings, I suggest that writing in a naturalistic environment requires the continual balance in activation of these two networks to find the optimal brain state for the given writing task. To my knowledge, these neuroimaging findings of writing as a creative process have yet to be extended to writing as a psychological intervention. Thus, I analyze my proposed model for writing in the context of Pennebaker’s (1997) psychological intervention, expressive writing, and its proposed mechanisms of action. I argue that the positive psychological effects associated with expressive writing are facilitated by the continual modulation between the DAN and DMN to find the optimal balance required of writing.

Introduction

Writing and the brain are inextricably linked. The historical prominence of mentally ill writers (Sylvia Plath, Ernest Hemingway, Virginia Woolf, to name a few) suggests that some association exists between psychopathology and writing. Additionally, it seems that many writers have an intuitive sense that writing is linked with psychology, even if their understanding of that link is fuzzy. For example, James Baldwin wrote, “When you’re writing, you’re trying to find out something which you don’t know” (as cited in Plimpton 1989). Even just this one quote reveals writing as the formation of knowledge and insight to further learning. Given these trends, it is worth investigating the neural basis to writing, and how these neural correlates might facilitate observed psychological effects associated with writing.

Presently, there is very little explicit neuroscientific research on writing. Psychological studies of writing explore writing as a tool for learning and as a psychological intervention (Pennebaker 1997), but are not based on neurological findings. Neuroscientific studies of language are dominated by verbal communication and reading, not on the generative aspect of writing (Hickock & Poeppel 2007; Fiez & Petersen 1998; Gernsbacher & Kaschak 2003). The handful of neuroimaging studies of a generative writing task focus on writing as a creative process (Shah et al. 2013; Liu et al. 2015), and are thus disconnected from examinations of writing as a tool for learning or healing. Thus, this paper bridges the gap between previously disconnected bodies of research, by applying findings of the neural correlates of writing to Pennebaker’s psychotherapeutic intervention “expressive writing.”

I will begin by presenting my interpretation of writing as a creative process, eventually putting forth my definition of writing as a behavioral and cognitive process. Next, I will outline Flower and Hayes’s (1981) cognitive processing theory of writing as a cognitive framework for my following neurological discussion of writing. In summarizing neuroimaging studies exploring writing and reviewing brain regions and networks implicated in writing, I synthesize these findings into a dynamic but unified model for writing. Next, I compare these findings to those of verbal creativity tasks, to isolate the aspects of creative generation specific to writing. Lastly, I apply these findings to a particular psychological intervention, expressive writing, to explore the psychological implications of writing.

To my knowledge, this paper is the first review of neuroimaging findings from generative writing tasks, and the first to apply these findings to expressive writing. In doing so, I argue that the diverse and dynamic processes required of writing are reflected in the continually modulated activations of the default mode network (DMN) and the dorsal attention network (DAN). I propose that the positive psychological effects associated with expressive writing are facilitated by the continued oscillation between the DMN and the DAN to find the optimal balance required of writing.

What is writing?

Before discussion of the neural basis of writing, it is first necessary to make sense of the many styles and forms writing encompasses to elucidate the behavioral meaning of writing. Ranging from a jotted-down grocery list to an affective poem to an extensively researched scholarly essay, writing can vary greatly. Specifically, in regard to the activity of writing, we can imagine that different writing contexts can influence every phase of the writing process. Starting with the motor processes required to physically generate a written text, writing can require handwriting or typing or even speaking, in the case of voice-to-text technology. The amount of time spent on, for example, a note to yourself on a to-do list, is far less than the time spent on a doctoral dissertation. A narrative story taking place in a fantasy world likely requires more imagination and divergent thinking than a scientific literature review. Yet, the literature review likely requires much more recall and synthesis of outside information. A songwriter might write a song in a matter of minutes from free associative idea generation, while a screenwriter might ruminate for hours on a single word choice. With respect to revision, a novelist might spend years editing, while never rereading their personal diary entries. Thus, writing contexts can influence the physical writing technique, the time spent on a writing project, the use of imagination or recall of outside information, the degree of free association, and the level of revision. In sum, writing can be understood as existing on a variety of spectrums. But despite these differences, what all these various writing contexts have in common is the generation of an original written text.

In the academic field of writing—which is of course a conceptualization of writing distinct from the more general act of writing—there is a common separation between creative and technical writing. For example, at Scripps College, the English department houses creative writing (consisting of fiction, poetry, creative nonfiction, and drama), whereas the writing and rhetoric department focuses exclusively on nonfiction prose genres. Of course, there is merit in this separation; creative writing requires a skill set distinct from evidence based technical writing. Yet, the line between these two types of writing is also blurred. For example, a newspaper op-ed might require both creative story generation and evidence based logical planning.

In *The Psychology of Creative Writing* (2010), scholars in creativity research offered perspectives on creative writing. Even within this book, creative writing has an amorphous definition. Daniel Nettle, a neuroscientist, puts forth a definition that requires creative writing to consist of fiction (p. 103). Martin Lindauer, a behavioral scientist, offered a more dynamic model of creative writing, in which the relationship between authors, readers, and written works determines the creativity of a work. This definition indicates that a writer by themselves cannot dictate if their writing is creative, suggesting that creative writing is a subjective categorization. The neuroscientific fMRI study I will later reference also uses a vague definition, in which creative writing requires "critical reflection" and "professional supervision" in the "acquisition of literary writing techniques" (Shah et al. 2013, p. 1089). This definition differs substantially from Nettle's, shifting the focus away from fiction and towards some kind of formality in the review of the writing. Of the definitions posed, I tend to side most strongly with Mark Runco's contribution to *The Psychology of Creative Writing*. Runco argues:

> Yet in one very important sense *every writer is creative*. Every writer interprets information in a constructive fashion. No writer simply finds sentences waiting to be transcribed onto his or her word processor, and individuals who merely copy something are not really writing — they are transcribing. If any composition is involved, and interpretation at all, there is room for creativity, and in fact a need for it. (p. 181)

Thus, since all generative writing requires creativity, the distinction should be dissolved between creative writing and other types of writing, at least for the purposes of this neurological discussion. Instead, creativity, defined as the "ability to originate something new and useful/meaningful" (Thys et al. 2014, p. 360), in writing can be understood as a spectrum, not a binary.

With these considerations in mind, for the purposes of this paper I define writing as the generation of original written text, a cognitive and behavioral process that is inherently creative.

Cognitive Theory of Writing

To ground my neurological discussion of writing in a cognitive model of writing, I am borrowing from Flower and Hayes's "A Cognitive Process Theory of Writing" (1981). I have chosen this model as my cognitive framework primarily because Shah et al. (2013) adopted this framework in their novel fMRI analysis of creative writing. Additionally, Flower and Hayes used protocol analysis based on audio recordings of participants "thinking out loud" throughout all stages of the writing process, from thinking and taking notes to final revisions. Based on this protocol analysis, the model they propose involves the writing process interacting with the rhetorical problem, the written text, and the writer's long-term memory. The writing process itself can be further split into hierarchically embedded subdivisions. "Planning" includes "generating ideas" (retrieving relevant information from working memory), "organizing" (adding meaningful structure to ideas generated), and "goal setting" (formation and maintenance of procedural and substantive goals). "Translation" consists of translating these organized ideas into written text. Lastly, "reviewing" consists of "evaluating" either the text or one's own organization of goals, and subsequent "revision" of the text and one's goals based on that evaluation.

Importantly, these processes do not occur in a discrete temporal order and instead are continually recurring and evolving. For example, while one is translating into written text, they might pause to evaluate their writing, causing them to adjust their goals or add a subgoal, perhaps requiring a revision or redirection of attention. A key aspect of Flower and Hayes's model is that the goals that drive the logic of a composition have the capacity to be revised or be elaborated upon with subgoals. Additionally, the maintenance and manipulation of these goals is reciprocally influenced by the written text itself. Goals elicit the generation, organization, and

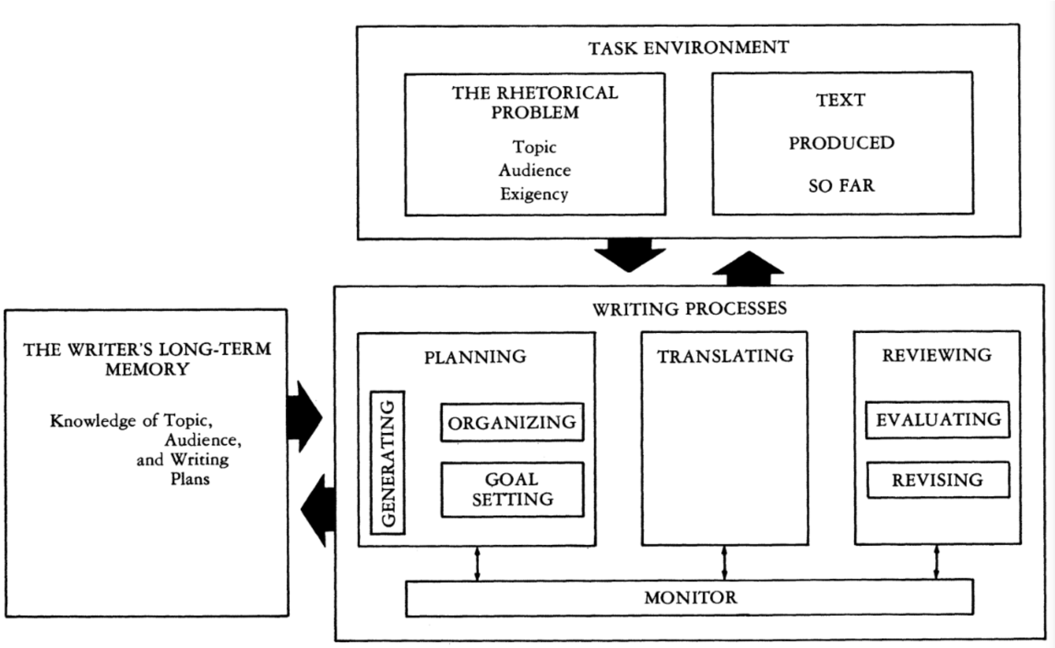

Figure 1. A cognitive model of writing. The writing process consists of planning, translating, and reviewing, in addition to their respective sub-processes. These processes are continually monitored by the writer through interactions with the writer's long term memory and the task environment. From "A cognitive process theory of writing," by L. Flower & J.R. Hayes, 1981, *College Composition and Communication, 32*(4), p. 370. Copyright 1981 by National Council of Teachers of English.

consolidation of ideas for translation into text, which can then be used to revise and regenerate new goals or subgoals (Figure 1).

The most important takeaway from this cognitive model is the dynamic nature of writing processes. Writing cannot be understood as the simple translation of one's ideas into text, but instead as a development of ideas by way of the continued evaluation and revision of both one's goals and the generated text.

Neuroimaging Studies on Writing

Thus far, few studies have explicitly investigated the neural correlates of creative writing. In this section, I will explain the methodology and imaging protocol of these studies, and briefly summarize their main findings. Following sections will include my analysis of these findings.

For the ease of comparison between studies, I will use Flower and Hayes's (1981) terms "planning," "translating," and "reviewing" to refer to the three stages of writing examined in these studies. While the specifics of these categorizations will vary between studies, I take planning to mean any work done before generation of written text, translating to mean the generation of written text, and reviewing to mean any work done after the generation of written text. Notably, these categorizations neglect a key component of Flower and Hayes's model: that the stages of writing are not temporally distinct. However, the temporal segregation of these processes is necessary for neuroimaging analysis to ensure which activations are associated with which cognitive process. Thus, as one interprets results from these studies, it is crucial to remember that a writer continuously oscillates between task states, planning and reviewing as they write.

In the first neuroimaging study to look at the generation of written text, Shah et al. (2013) used a novel fMRI creative writing paradigm to identify neural associations of creative writing. Previous studies, such the fMRI analysis of story generation by Howard-Jones et al. (2005), used word sets as starting points for internal story-generation. Yet, the paradigm from Shah et al. (2013) uses actual handwriting to generate a written continuation of a given literary passage. These facets of the paradigm ensure that written creative generation specifically is being investigated. Based on a theoretical framework from Flower and Hayes (1981), Shah et al. (2013) split their writing task into "brainstorming" and "creative writing," which correspond with planning and translating, respectively. Control paradigms of "reading" and "copying" were also included to isolate generative creative processes involved in planning and translating, respectively.

Shah et al. (2013) found that network activation during planning predominantly consisted of the bilateral IFG, left parieto-temporal regions, PFC, and dACC. This fronto-parieto-temporal brain activity suggests the involvement of divergent thinking, cognitive flexibility, verbal fluency, and idea selection. Planning additionally showed activations in the primary visual cortex and motor regions, such as the left SMA and dPMC, suggesting that planning extends beyond cognitive organization to visual imagination and anticipation of future motor outputs. The translating task activated regions associated with handwriting, language processing, memory retrieval, semantic integration, free association, and spontaneous cognition. Contrast between translating and copying revealed regions associated with memory retrieval, including bilateral temporal pole, hippocampi, and posterior cingulate cortex. Lastly, a correlation analysis between the creativity index and the contrast between translating and copying showed predominantly left lateralized activations in the superior temporal gyrus, the temporal pole, and the IFG, positively correlated with the creativity index. Together, these results indicate a fronto-parieto-temporal brain network involved in the generation of a written work (Figure 2).

Expanding upon this study, Erhard et al. (2014) used the same fMRI writing paradigm to examine creative writing in experts and novices. Building upon Flower and Hayes's (1981) argument that novice writers tend

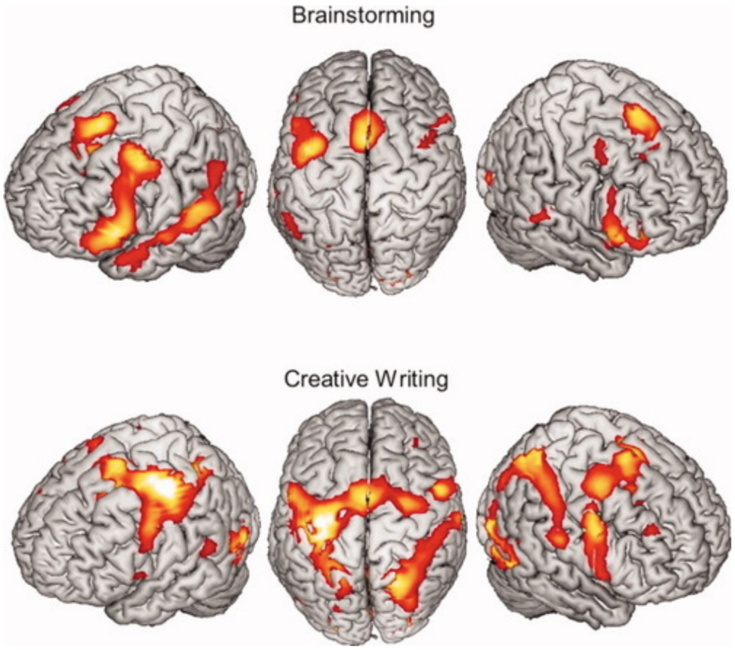

Figure 2. Cortical activations for the main effects of the planning task (top panel) and translating task (bottom panel). From "Neural correlates of creative writing: An fMRI study," by C. Shah et al., 2013, *Human Brain Mapping, 34*(5), p. 1094, Copyright 2011 by Wiley Periodicals, Inc.

towards free-association while experienced writers use organized goals to form the logical framework of their composition, the researchers aimed to compare these two groups to identify neural correlates of these advanced cognitive processes in experienced writers. In the translating task, experts showed increased bilateral dlPFC, left superior mPFC, and left caudate activation compared to novices. This increased activation of the caudate nucleus implicates the basal ganglia and suggests cognitive functions such as skill automatization and working memory training. With the additional removal of the copying control from translating, experts showed increased activation in the right middle cingulate. Additionally, the creativity index was positively correlated with right cuneus activation in experts. When reading control results were subtracted from planning, experts showed activation of the right putamen, right insula, left SMA, and the right primary motor context. This activation of regions involved in the cognitive skills of speech production and the motor skills of handwriting indicates that during planning, experts might anticipate the generative aspects of writing (Figure 3).

Figure 3. Cortical activations in expert writers for the main effects of the planning task (top panel) and the translating task (bottom panel). From "Professional training in creative writing is associated with enhanced fronto-striatal activity in a literary text continuation task," by K. Erhard et al., 2014, *NeuroImage, 100*, p. 19, Copyright 2014 by Elsevier Inc.

Another neuroimaging study looked specifically at poetry composition to explore neural correlates of creative process, product, and expertise (Liu et al. 2015). In the translation phase of poetry composition, activations increased in the mPFC, but decreased in the dlPFC and the IPS. Together, the dlPFC and IPS make up the dorsal attention network (DAN), a frontoparietal network (Corbetta & Shulman 2002) that plays a role in top-down attentional control. Thus, the deactivation of this network in the generative translating phase suggests an attenuation of top-down functioning allows for more spontaneous creativity. Compared to the control condition of recitation of memorized facts, the translating task showed little differences in mPFC activity, but less activity in the DAN. This comparison between creative and non-creative spontaneous generation suggests that modulation of the DAN is specifically associated with the creative improvisation necessary for poetic composition.

The reviewing phase showed little differences in mPFC activation, but showed an increase in activation in the dlPFC, IPS, and precuneus, compared to the generation phase. This finding suggests that the mPFC is necessary for cognitive processes involved in both translating and reviewing phases of poetry composition, but that activation of the DAN is modulated depending on the degree of top-down control required. A connectivity analysis revealed two distinct networks: 1) cluster of the mPFC with perisylvian language area and 2) the DAN. The two phases of poetry composition showed reciprocal connectivity patterns, such that during translating the two networks were significantly anti-correlated, while during revision that anti-correlation was attenuated. These activity and connectivity patterns illustrate the dynamic and diverse processes that writing can encompass, depending on the creativity or attentional control required of the writing project. Importantly, while this study showed these activation patterns as temporally distinct, in a real-world poetry composition context these processes are likely more flexibly intertwined as one oscillates between translating and reviewing.

Liu et al. (2015) also explored differences between published poets who have completed at least one year of an MFA (experts) and a group of controls (novices). While experts and novices showed the same general connectivity patterns, experts showed a stronger deactivation

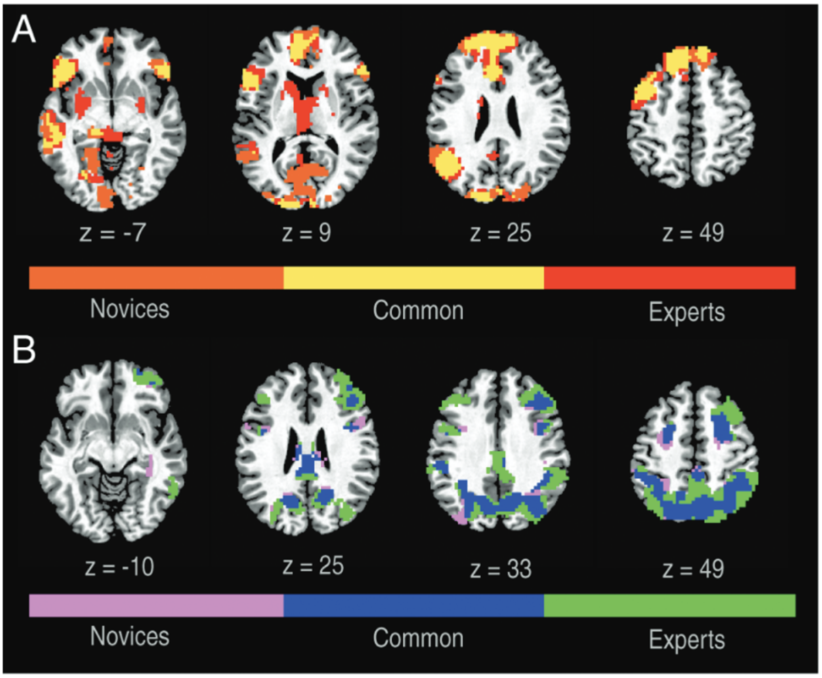

Figure 4. Conjunction of brain (A) activations and (B) deactivations associated with the contrast between the translating task and a non-creative recitation control task between experts and novices. Colors represent brain activity unique to experts, novices, or both. From "Brain activity and connectivity during poetry composition: Toward a multidimensional model of the creative process," by S. Liu et al., 2015, *Human Brain Mapping, 36*(9), p. 3361, Copyright 2015 by The Authors.

of the dlPFC and IPS during translating, suggesting that expert poets rely less on top-down control during translating. Additionally, experts showed greater activation of the dorsal caudate and dorsomedial thalamus during the generation phase (Figure 4). With the dlPFC, these subcortical activations constitute the dorsolateral prefrontal corticostriatal circuit proposed by Alexander et al. (1986). The involvement of these subcortical structures suggests that in experts, the striatum is engaged to mediate routinized and automatic behaviors, rather than translating being driven by top-down cortical control.

After analyzing the role of process and expertise in the neural correlates of poetry composition, the researchers analyzed the product poem for both craft (defined as the use of poetic devices) and linguistic creativity (defined as the innovative use of craft elements). As expected, experts showed more successful use of both craft and literary creativity. Individuals whose poems showed a more effective use of craft elements also showed a greater coupling between the mPFC and the left perisylvian language regions, inferior parietal lobule, the precuneus, and the PCC. These regions—specifically the inferior parietal lobule, precuneus, and PCC—are elements of the default mode network, which is thought to underlie spontaneous cognitive processes, such as daydreaming or mind wandering (Raichle 2015). That this network shows greater connectivity with perisylvian language regions suggests that spontaneous ideas are more easily translatable into text in individuals who successfully use more poetic devices. In experts, linguistic creativity was associated with a decreased connectivity between the dlPFC and auditory, somatosensory, and motor regions; concomitantly, there was greater connectivity between these latter three regions and the orbitofrontal cortex. This shift in connectivity suggests that linguistic creativity relies more on emotional regulation and decision making, facilitated by the orbitofrontal cortex which has stronger connections to the limbic system. Interestingly, this connectivity pattern associated with linguistic creativity was reversed in novices, such that novices with greater linguistic creativity showed greater connectivity between the dlPFC and sensory regions. This suggests that while experts are more able to access emotional control for innovative use of poetic devices, novices must rely more heavily on top-down processing facilitated by the dlPFC.

Together, these results are synthesized into a model proposed by Liu et al. (2015), that encompasses process, expertise, and product. Both the mPFC and the DAN connect to down-stream regions related to language, sensorimotor, and limbic process; however, the mPFC drives intrinsic activation of these regions throughout the entire poetry composition process, while activation of the DAN is phase dependent and thus when deactivated facilitates spontaneous generation. General connectivity patterns remained consistent between experts and novices, with experts showing stronger deactivation of the DAN and activation of the caudate and thalamus. Lastly, downstream regions showed greater connectivity with the mPFC and attenuated connectivity with the DAN in individuals who demonstrated more successful and innovative use of poetic devices.

The final neuroimaging study used mobile scalp EEG during a 16-week university writing workshop to characterize the stages of creative writing (Cruz-Garza et al. 2020). Unlike the previous fMRI studies, the mobile EEG data collection technique allows for naturalistic data collection, in which participants are able to move freely in their environment throughout the writing process. Based on writing prompts built on experiential observations, participants physically interacted with outdoor spaces (planning) to generate writing (translating) that explores their bodily experience. Throughout this process, EEG data was collected from bilateral frontal and parieto-temporal regions, as well as video recordings from body cameras. Using generalized partial directed coherence as a measure of connectivity, the findings suggest higher functional activity from anterior frontal regions toward parieto-temporal regions during the planning stage. The authors suggest that during planning, higher order frontal regions "integrat[e] the experience" (p. 6), while the parieto-temporal regions process multisensory inputs and integrate episodic emotional memory; although it is left unclear what kind of higher order frontal functioning might be involved in this process. Thus, during planning, frontal regions might integrate experiential information that is then processed in the translating stage, which showed opposite directionality from the right parieto-temporal and left frontal electrodes, (although this finding did not reach statistical significance).

In all, these neuroimaging findings suggest left lateralized network activations, that consist of communication between frontal executive control networks and downstream language and motor regions. These activation patterns will be discussed more extensively in the following section. Additionally, these studies exemplify some common limitations when attempting to identify neural activations associated with writing. The specificity of fMRI analysis comes at the cost of naturalistic writing conditions, while the ease of EEG recording comes at the cost of neural specificity. Further, one's natural writing processes might be disrupted due to the necessity of segregating writing tasks during imaging procedures. Comparison between studies is also limited by the diversity in writing tasks, which vary from continuation of a provided story to poetry composition. Thus, future studies should be done to expand the body of research on different writing types to further elucidate how the demands of a writing task can influence activation patterns.

Region and Network Activations

Medial Prefrontal Cortex (mPFC)

The mPFC (Figure 5) was activated during planning, translating, and reviewing stages of writing (Shah et al. 2013; Liu et al. 2015; Cruz-Garza et al. 2020). A highly diverse region, the mPFC is associated with functions such as motivation (Kouneiher et al. 2009), self-generated action and self reflection (Passingham et al. 2010), unconscious decision making (Soon et al. 2008), and memory (Euston et al. 2012). In the context of writing, these findings suggest that the consistent activation of the mPFC is involved in the motivation and execution of written work, including cognitive control of decisions and integration of recalled information. With respect to memory, Euston et al. (2012) proposed a framework of the mPFC's role in memory, such that "contextual control of affect or action" (p. 1065) requires the mPFC for encoding, recall, and consolidation of memories. Importantly, this integration

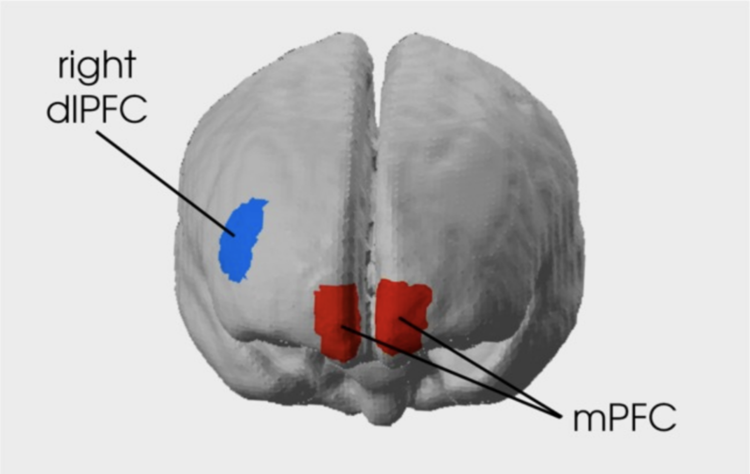

Figure 5. Representations of the mPFC (red) and dlPFC (blue) based on fNIRS analysis. From "A functional near infrared spectroscopy (fNIRS) replication of the sunscreen persuasion paradigm," by S. M. Burns et al., 2018, *Social Cognitive and Affective Neuroscience, 13*(6), p. 632, Copyright 2018 by The Authors.

of multisensory contextual information is necessary in deciding the appropriate action or emotional response, meaning that the mPFC is central in the decision-making and synthesis of information required for writing. These cognitive processes are elements of the hierarchical goal-setting framework of writing proposed by Flower and Hayes (1981). That the mPFC is more strongly activated in expert writers (Erhard et al. 2014), suggests that repetitive practice of writing can potentiate the activation of these goal-oriented, motivating processes necessary for the generation of written text. The mPFC also has crucial network connections to perisylvian language regions and the DMN, which will be discussed in following sections.

Dorsolateral Prefrontal Cortex (dlPFC)

The dlPFC (Figure 5) was activated during planning and translating during story-generation tasks (Shah et al. 2013; Cruz-Garza et al. 2020). However, during poetry composition the dlPFC was deactivated during the translating stage and activated during the reviewing stage (Liu et al. 2015). To understand the relevance of this selective deactivation, we must first understand some functional associations of the dlPFC. Kouneiher et al. (2009) propose a model in which prefrontal executive functioning is hierarchically controlled, such that medial regions send “motivational incentives” (p. 939) and contextual memory information to regulate top-down decision making in lateral regions. Petrides (2005) argues that the dlPFC, specifically, is involved in monitoring and manipulating stimuli in working memory. This monitoring and manipulation constitutes planning and organization of information, and thus implicates the dlPFC in “conscious active control of planned behavior and cognition” (Petrides 2005, p. 789). Thus, the dlPFC can be understood as top-down cognitive control, encompassing attentional planning.

Consequently, the deactivation of the dlPFC observed in Liu et al. (2015) during the translating stage of poetry composition suggests an attenuation of these top-down planning functions. Since the generation of poetry likely requires an increased use of creative processes, such as insight, divergent thinking, and spontaneous generation of ideas, the deactivation of the dlPFC might facilitate these types of creative processing. That is, the top-down attentional driven planning associated with the dlPFC may interfere with such creative processes. Since the other fMRI writing studies did not assess deactivations (Shah et al. 2013; Erhard et al. 2014), Liu et al. (2015) is the only study to have found this deactivation of the dlPFC during a writing task. However, notable differences between the two writing paradigms—Shah et al. 2013 compared planning and translating, while Liu et al. 2015 compared translating and reviewing—may have contributed to the differences in the findings related to the dlPFC. Liu et al. (2015) argue that their translating phase is most similar to planning in the other experiment because they both require the highest degree of idea generation. However, comparing this generative improvisation phase to a translating task is inherently different than to a reviewing task; revision does not require as much creative generation, and likely relies more on top-down decision-making processes. Thus, more information is needed—specifically the inclusion of a reviewing task and measurement of functional deactivations—to conclude that the Shah et al. (2013) findings are contradictory to Liu et al. (2015). Like the mPFC, the dlPFC is also a part of key networks, one of which will be discussed in a following section.

Default Mode Network (DMN)

The DMN, first discovered by Shulman et al. (1997), decreases in activity during task states, suggesting its role in ongoing or intrinsic processes. The DMN consists of the vmPFC, dmPFC, PCC/adjacent precuneus, and lateral parietal cortex (Raichle 2015, Figure 6). This network of regions is characterized by a “baseline of high activity” (p. 440), which is either intensified or attenuated to meet the requirements of a cognitive task. Additionally, Andrews-Hanna et al. (2014) argues that the DMN is particularly involved in self-generated thought, a process facilitated by subsystems of the DMN. The functional relationship between these subsystems involves processes such as recall of autobiographical information and mentalizing, which are integrated in core regions to represent personally relevant information. Notably, the hippocampus showed network connectivity to the medial temporal subsystem, assisting in the recall of episodic information. Additionally, the PCC was proposed as integrating behaviorally relevant information from memory and/or perception in bottom-up attentional control (Andrews-Hanna et al. 2014). Taken together, these findings suggest that the DMN is

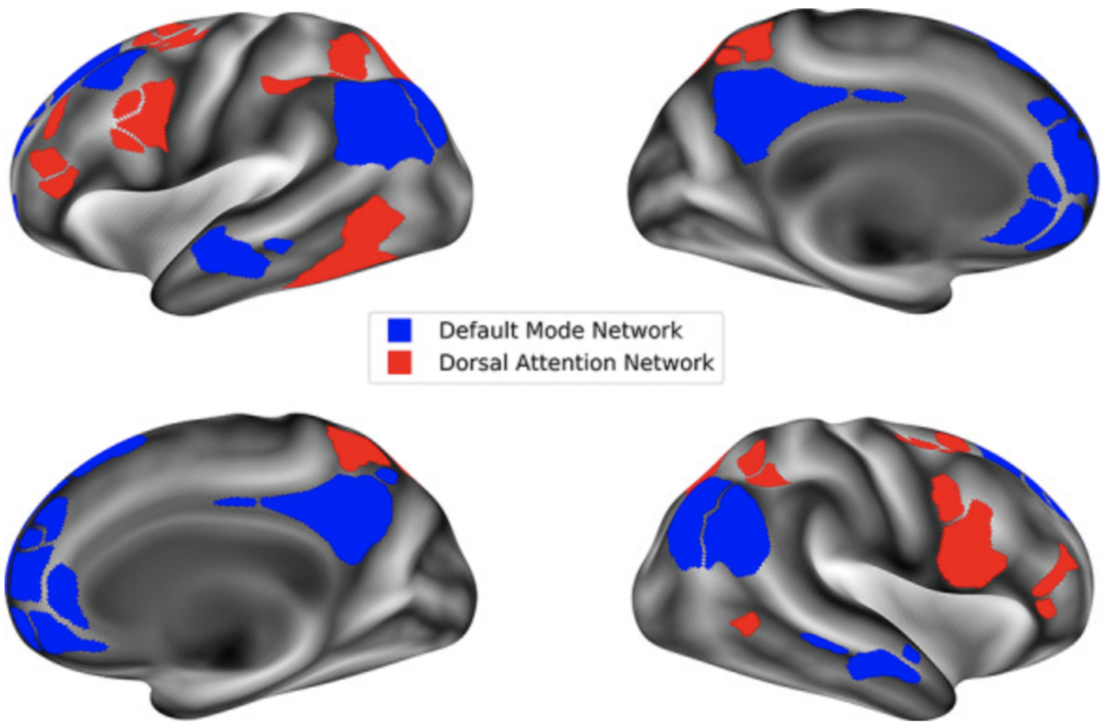

Figure 6. Representations of the DMN (blue) and DAN (red) based on resting state fMRI. From “Investigation of psychiatric and neuropsychological correlates of the default mode network and dorsal attention network anticorrelation in children,” by M. Owens et al., 2020, *Cerebral Cortex, 30*(12), p. 6087, Copyright 2020 by The Authors.

essential in the spontaneous generation of personally relevant information, a skill that is likely critical in more personal forms of writing, such as expressive writing. Furthermore, mentalization, defined as “the metacognitive process of interfering or reflecting upon the mental states of other people and/or one’s self” (Andrews-Hanna et al. 2014, p. 9), includes self-generated cognition related to understanding another’s mental state, and is therefore likely to be essential in forms of writing that require taking another’s perspective, such as fictional storytelling.

As previously outlined, the mPFC is activated consistently in writing, and is more strongly activated in experts. Additionally, a comparison of translating to a control task (copying) showed significant activation of the PCC and hippocampus (Shah et al. 2013); this suggests that the activation of the DMN might contribute to the creative aspects of generating an original written text, as opposed to copying a pre-existing text. The particular activation of the hippocampus and PCC suggest that these creative processes specifically involve integration of salient information recalled from episodic memory to generate the written creative output. In poetry composition, greater measures of craft in the written product were associated with a stronger functional connectivity between the mPFC, the inferior parietal lobule, the precuneus/PCC, and left perisylvian language regions (Liu et al. 2015). This association between the DMN and language regions suggests that spontaneous self-generated abstract ideas are more easily translated into language in writers who used poetic devices more successfully. In this experiment, craft elements were assessed by a panel of three accomplished poets and were rated in terms of four categories (sound, form, figurative language, and sensory language) on a binary scale, such that the panel could indicate the presence or absence of craft elements. In addition to this positive binary scale, the panel could also redact points if clichés or redundancies were identified. It is worth noting that these assessments of poetic craft are inherently subjective and thus are not empirical scientific measures of literary creativity. For example, how one reader defines a cliché might differ significantly from another and I would argue that use of cliché is not antithetical to a creatively written poem. However, even despite this subjectivity, the general finding that these assessments of craft were associated with connectivity between the DMN and language regions still indicates that individual differences in functional connectivity can be reflected in qualities of the written product. In all, these findings elucidate the role of the DMN in spontaneous self-generated thought that is selectively accessed during writing processes. The modulation of the DMN importantly involves interactions with and balance between other executive control networks, such as the dorsal attention network.

Dorsal Attention Network (DAN)

During the translating stage of poetry composition, Liu et al. (2015) found concomitant deactivations in the dlPFC and the IPS. Thus, the dorsal attention network (DAN) is of interest in this discussion because it is comprised of the IPS and frontal eye fields and is functionally correlated with prefrontal regions (Fox et al. 2006, Figure 6). The DAN is thought to functionally balance the DMN, such that DAN activation increases during attention driven tasks, and is accompanied by decreases in DMN activation (Raichle 2015). This anti-correlative relationship between the DAN and the DMN was aptly illustrated by Raichle's metaphor of "losing one's self in one's work" (p. 442), in which attention driven top-down thinking overpowers spontaneous self-generated thinking.

The DAN is specifically involved in stimulus and action selection, involving monitoring and manipulation of information in the working memory (Corbetta and Shulman 2002). These attention driven cognitive processes are predictably involved in organizational aspects of the writing process. Thus, the deactivation of the DAN in Liu et al. (2015) reflects the attenuation of top-down attentional control, and consequently an increased reliance on the DMN. The balance between these two networks is thought to be critical in determining creativity. Raichle and colleagues examined this balance with respect to impulsivity—distinct, but closely related to creativity. Impulsive juveniles showed greater connectivity between the DMN and premotor regions, whereas controls showed functional connectivity between premotor regions and the DAN. A further analysis of individuals across a wide age span found that younger people showed a connectivity more similar to the impulsive group and older people showed a connectivity more similar to the control group (Shannon et al. 2011). From these findings, we can conclude that the functional balance between these two networks can give rise to complex psychological traits, such as impulsivity, and can develop over one's lifetime.

The balance between the DMN and the DAN can also be applied directly to creativity. In a conceptual exploration of creativity, Runco (2010a) argues that creativity can be viewed through the single concept of "optimization"—that creative people use "freedom of thought" only to optimal levels. Mok (2014) extends Runco's conceptual argument to the balance between these two neural networks, arguing that optimization can be understood as "the capacity to achieve, on a minute to minute basis, optimal balance between control network activity and default network activity" (p. 3). Therefore, the ability to modulate between the DMN and the DAN is essential in the optimization required of creative thinking. Additionally, as suggested by results from Shannon et al. (2011), this dynamic functional network organization can develop over one's lifetime. As shown in Liu et al. (2015), writing requires both the creative generation that attenuates the DAN and the attentional planning that activates it. Therefore, writing can be understood as the continual adjustments between the DAN and the DMN in an attempt to find the optimal balance for the particular sub-goal (Flower and Hayes 1981) of the writing process.

Liu et al. (2015) also found that experts showed a greater deactivation of the DAN in the generation of poems, indicating that writing practice can allow for a greater ability to shift the balance towards spontaneous generation when the writing task requires it. Although Shah et al. (2013) did not measure deactivations, the activation of both the DAN and the DMN in both planning and generation suggests that balance between the two systems is also involved in their story generation task. More research on different types of writing tasks—e.g. expressive writing, technical writing, fiction—could lend more specificity to the understanding of how these networks are selectively balanced based on the writing task. Perhaps more imaginative genres, such as poetry or fiction, rely more heavily on the DMN, while other more evidence based writing relies more on the DAN.

Language Network

Generally, language control is left lateralized in fronto-temporal regions, with some right hemisphere homologues implicated as well (Gernsbacher & Kaschak 2003). Shah et al. (2013) found activations in the bilateral IFG and the left superior temporal sulcus (STS) during both planning and translating. The left IFG, which includes "Broca's area," is involved in phonological, syntactic, and semantic processing of information (Gernsbacher & Kaschak 2003). The left STS is involved in word perception and retrieval from memory (Price 2012). The left temporal pole was additionally activated during planning (Shah et al. 2013), and is associated with sentence and narrative comprehension (Gernsbacher & Kaschak 2003). These findings confirm that multiple stages of writing require language processing on multiple levels, from phonology to entire narratives. However, it is important to note that Shah et al. 2013 did not report contrasts between planning and the control condition ("reading"), so conclusions cannot be made about whether activations during planning in language regions are exclusive to generation of language or encompass activations from reading the prompt text. Liu et al. (2015) also found activations of the IFG, STS, and fusiform gyri during the generation phase, and that these language regions showed significant functional connectivity with the mPFC. This coupling of language regions with the mPFC, which is also connected to the DMN, suggests that the self-generated motivational control exerted while writing has specific downstream effects on language processing. In their argument against the "Classic model" of language processing, and its associated Broca's and Wernicke's areas, Tremblay and Dick (2016) instead propose a model of perisylvian long association fiber pathways that connects a network of cortical language processing regions. In doing so, the authors advocate that language regions be studied in interaction with other functional systems to encompass these broad network connections. Thus, the concomitant activation of the DMN and the mPFC with language regions suggest that, in the context of generation of a written text, language processing must be understood as intertwined with other creative and executive processes.

Basal Ganglia

Two studies found that experts showed greater activation of subcortical structures, particularly the caudate and thalamus, during writing processes (Liu et al. 2015; Erhard et al. 2014). The activation of these regions implicates the basal ganglia, a set of subcortical nuclei that subserve movement, behavior, and emotions. Particularly, the basal ganglia are thought to be involved in habit formation, reward-related behavior, and emotions (Lanciego et al. 2012). Specifically, Saling & Phillips (2007) argue cognitive resources are shifted towards the basal ganglia during "automaticity," defined as less effortful and more efficient processing. Their model of automaticity involves the deactivation of cortical regions and the activation of the basal ganglia, indicating that the acquisition of automaticity requires strengthening of connections within the basal ganglia. Additionally, the dorsal caudate has critical connections to both prefrontal cortical regions and the thalamus, forming the dorsolateral prefrontal corticostriatal-thalamocortical circuit first proposed by Alexander et al. (1986). This circuit contributes to decision-making, particularly selection of goal-directed actions based on reward (Balleine et al. 2007). More specifically, the caudate itself is thought to evaluate "action-outcome contingencies" to select for the appropriate sub-goal, by selectively sending activation to the appropriate prefrontal cortical region, facilitated by parallel corticostriatal circuits (Alexander et al. 1986; Grahn et al. 2008, p. 150; Figure 7). The organization of sub-goals is a key aspect of the writing process (Flower & Hayes 1981), and thus it makes sense that functional connections between the basal ganglia and frontal cortical regions are strengthened in more experienced writers.

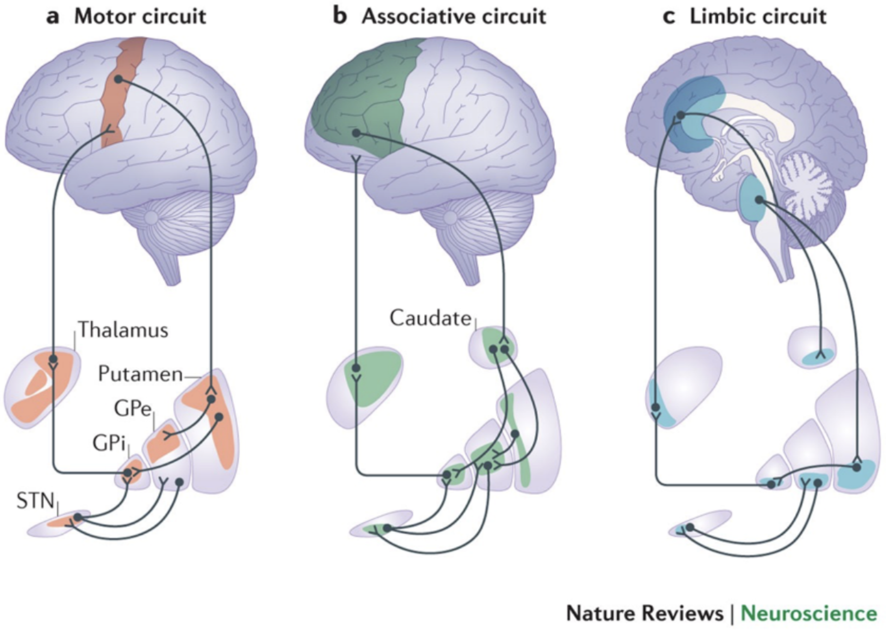

Figure 7. Parallel corticostriatal circuits. The striatum and thalamus receive inputs from a variety of cortical and subcortical areas, including the dlPFC and orbitofrontal cortex. From "A fronto-striato-subthalamic-pallidal network for goal-directed and habitual inhibition," by M. Jahanshahi et al., 2015, *Nature Reviews Neuroscience, 16*, p. 720, Copyright 2015 by Macmillan Publishers Limited.

Liu et al. (2015) additionally found that when the dorsal caudate and dorsomedial thalamus were activated, the DAN was deactivated during poetry generation. This reciprocal connectivity pattern aligns with Saling & Philips (2007) model of automaticity, such that the activation of the caudate represents a shift of mental resources away from top-down attentional control and towards automatic, less effortful control. Additionally, Liu et al. (2015) showed a greater functional connectivity between the orbitofrontal cortex (as opposed to the dlPFC) and sensorimotor regions in experts whose poems showed greater linguistic creativity. Since the caudate and thalamus mediate the deactivation of the DAN, this functional reorganization of prefrontal regions might also be a result of the caudate initiating a shift in cognitive resources. A lateral orbitofrontal corticostriatal-thalamocortical circuit also includes the caudate (Alexander et al. 1986) and can thus account for this shift from the dlPFC to the orbitofrontal cortex in experts. However, since Liu et al. (2015) did not report associations between the orbitofrontal cortex and basal ganglia structures, we cannot make any conclusions about the role of the caudate in this functional reorganization. Generally, these findings suggest that recurrent use of the goal-oriented decision making in the basal ganglia during writing can strengthen its functional connectivity and allow writers to rely more on its subcortical processing to achieve automaticity.

A Unified Model for the Neural Basis of Writing

Given these analyses of neuroimaging results associated with writing, I propose a unified model for writing that consists of a functional balance between the DAN and the DMN, mediated by the basal ganglia, that has downstream effects on language and sensorimotor regions for the execution of writing (Figure 8). As described above, the balance between the DAN and the DMN can facilitate creative idea generation, such that the appropriate balance between top-down processing and spontaneous self-generated thought can assist in optimization of creative cognitive processes. Activation of the DAN is attenuated when the specific writing sub-goal requires more spontaneous generation, as shown during the generation of poetry (Liu et al. 2015), a process that requires less logic driven generation and more emotional, rhythmic, and imaginative processing. However, even within poetry composition, changes in sub-goals can modulate the balance between the DMN and DAN, as shown in the increase in activation of the DAN during the reviewing task (Liu et al. 2015). As outlined by Flower and Hayes (1981), the stages of the cognitive processes involved in writing occur in a non-linear manner. That is, revision does not occur after all the generation of written text has been completed; instead, we

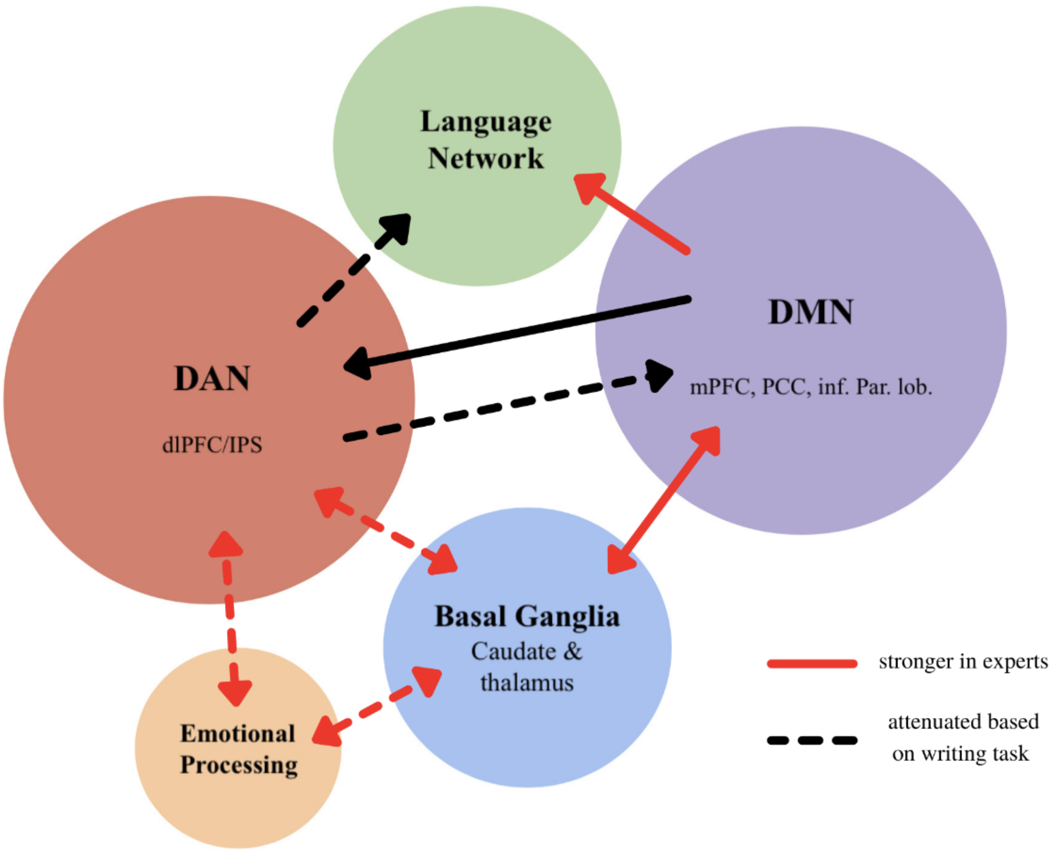

Figure 8. A unified model for the neural basis of writing. The DAN and DMN functionally balance each other, mediated by basal ganglia structure, and with downstream effects on language regions. Activation of DAN can be attenuated (dotted arrow) based on the writing task to facilitate spontaneous generation. Functional connectivity between the DMN and the language network is stronger in experts (red arrow). Experts additionally show greater functional connectivity with the basal ganglia, allowing for automaticity. The basal ganglia can also use parallel corticostriatal circuits to facilitate switching between the DAN and other executive control networks, such as the orbitofrontal cortex involved in emotional processing.

revise, evaluate, organize, and set goals throughout all aspects of the writing process. Therefore, writing requires the constant modulation of the balance between spontaneous generation (DMN) and attentional control (DAN).

The selective prioritization of one or the other of these networks is additionally mediated by basal ganglia, which integrates reward based and goal-oriented information to select the appropriate corticostriatal-thalamocortical circuit. In Liu et al. (2015), the concomitant activation of the basal ganglia with deactivation of the DAN suggests that the basal ganglia is involved in regulating the balance between these two opposing networks. In expert writers, this regulatory effect of the basal ganglia is strengthened (Erhard et al. 2014; Liu et al. 2015), indicating that writing practice can allow for greater reliance on subcortical structures that support automaticity of these cognitive processes.

Additionally, Liu et al. (2015)'s finding that the deactivation of the DAN was accompanied by the greater functional activation of the orbitofrontal cortex, implies that the reorganization of cognitive resources is not exclusive to the balance between the DMN and the DAN, and extends to other information processing regions of the brain. Although no writing studies reported connectivity between basal ganglia and the orbitofrontal cortex, the existence of a parallel lateral orbitofrontal corticostriatal-thalamocortical circuit (Alexander et al. 1986), provides evidence that the basal ganglia mediates other shifts in cognitive resources, in this case from the dlPFC to the orbitofrontal cortex. This activation of the orbitofrontal cortex also has implications for the kind of information being processed; specifically, emotional information due to the connectivity between the amygdala and the orbitofrontal cortex (Kringelbach 2005). Therefore, this reorganization might represent the attenuation of top-down attentional control and the replacement of that control with processing more closely associated with emotional integration. Since this connectivity pattern with the orbitofrontal cortex was specifically observed in experts with greater linguistic creativity in their poems, perhaps this measure of linguistic creativity (which, as discussed with assessments of craft in poems, is an inherently subjective measure) is associated with greater integration of emotional information in the generation of poems. Like with the balance between the DMN and the DAN, the shift between executive control cognitive resources is likely a result of goal oriented selection, potentially mediated by the basal ganglia, depending on the requirements of the writing task. While I focused my discussion here on the orbitofrontal cortex, finely tuned shifts in the balance between executive control networks can occur across a wide span of cortical regions. Therefore, while in this case increased reliance on emotional processing was indicative of linguistic creativity in poetry, other writing tasks might shift cognitive resources elsewhere. In all, the balance of top-down attentional control with other cognitive processes, which is mediated by subcortical structures, serves the manipulation and execution of sub-goals related to the specific writing task.

The final piece of this model is how these network systems influence the downstream language regions required for the linguistic generation of a written text. Both the DMN and the DAN showed functional connectivity to critical perisylvian language regions, indicating that the balance between these systems has downstream effects on the language output. Particularly, since stronger coupling between the mPFC/DMN and perisylvian language regions was associated with greater use of craft elements (Liu et al. 2015), it seems that the network control of these language regions influences characteristics of written product produced. In this case, control by the DMN might facilitate the translation of spontaneously generated ideas into text. Yet, functional connectivity between the dlPFC/DAN and language regions, as shown in Shah et al. (2013), might facilitate top-down planning of text generation. Thus, the balance of the DMN with the DAN (or other executive control networks), as mediated by basal ganglia corticostriatal-thalamocortical parallel circuits, has downstream effects on language regions to execute specific subgoals within the writing process. This balance and the degree of reliance on the basal ganglia can be influenced by expertise, suggesting that writing practice can allow for greater modulation of these systems and even automaticity in the cognitive process required of writing.

Comparison to Verbal Creativity

While these findings indicate a dynamic functional organization of neural systems that facilitates creative generation in writing tasks, it is important to also consider what aspect of these findings is specific to writing, as opposed to verbal or mental linguistic creativity. To do so, I will be focusing on two studies that parallel Shah et al. (2013)'s written story generation task and Liu et al. (2015)'s poetry generation task, but without the written aspect. By making this comparison, I elucidate regional associations with written generation that are distinct from general linguistic creativity.

Howard-Jones et al. (2005) studied story-generation from a set of words to study semantic creativity. In this design, participants were asked to internally generate a story based on a set of either related or unrelated words. Since researchers determined that the motor activity required of verbal telling of the story would interfere with imaging results, participants instead recalled their stories after leaving the scanner. Therefore, this task consists of a similar story generation task, but is missing the written element of Shah et al.'s (2013) design. The main findings of the experiment suggest associations between creative effort and activations in medial frontal regions and the anterior cingulate cortex. Most specifically, the right medial frontal gyrus showed activation when using unrelated word sets in people aiming to be creative. Thus, this region is implicated in the semantic integration required of generating a simple narrative around these words. While these findings are not at odds with Shah et al. (2013), they represent a much more narrow network for linguistic creativity, centered around medial frontal regions and the ACC. As was previously outlined, the mPFC is important for motivational control and context-based decision making. Additionally, the ACC has diverse functions and has been proposed as integrating social context with empathy to inform decision making (Lavin, et al. 2013). As is the case in writing processes, the activation of these medial frontal regions suggests the involvement of episodic recall, monitoring, and decision-making. However, the additional activations of the dlPFC and the PCC during generation shown in Shah et al. (2013) reveal other more functionally and anatomically expansive networks in written generation. The activation of each of these regions implicates both the DAN and the DMN, indicating that written story generation specifically relies on a balance between spontaneous generation and top-down executive control. These differences in activation between internal and written story generation might come as a result of the act of writing itself; as outlined in Flower and Hayes (1981) the consolidation of ideas into a written text might force a reorganization of self-generated goals, which could be reflected in shifts in activity patterns between the DAN and the DMN. However, more explicitly comparative studies are required to make conclusions about the specific effect of written expression in the network activations associated with story-generation.

Prior to their investigation of poetry composition, Liu and colleagues conducted an fMRI analysis of lyrical improvisation by comparing improvised rap to memorized pre-written rap (Liu et al. 2012). The main findings paralleled that of the generative task in poetry generation, such that activations in the mPFC were accompanied by deactivations in the dlPFC. This piece of evidence supports the theory that deactivation of the DAN facilitates spontaneous generation, like that of lyrical improvisation. Additionally, innovative performance quality, as measured by a set of subjective measures of creative use of language and rhythm, showed greater increases in language regions, the left mPFC, and the PCC. Similar to findings associated with craft in poetry composition, a stronger coupling between language regions and the DMN might facilitate the translation of self-generated ideas into language. Lastly, while the dlPFC showed general deactivation during the improvisation exercise, comparisons of activations at the first measure versus the last measure of the improvised segment revealed a greater activation of the DAN by the end of the segment. It is unclear precisely why this shift towards attentional processing occurs during rap improvisation, but it represents a greater focus on rule-based actions to wrap up a verse. Whereas the beginning of lyrical improvisation might require an initial motivational drive of self-generated ideas, the end might require more attention paid to technical qualities, such as rhyme schemes or meter. Taken together, the greatest differences between the findings associated with verbal lyrical improvisation and with poetry composition lie in the balance between the DMN and the DAN. While rap showed some reactivation of the DAN, revision of poems showed a much more reliable and consistent activation of this top-down attention network. Given that in writing, revision and other organizational and evaluative processes occur throughout writing processes (Flower and Hayes 1981), the modulation between processing systems must occur reliably and frequently. On the other hand, purely verbal generation does not require the constant revision of what has been already generated, at least in part because of the ephemeral nature of the spoken word. I argue that even just the simple temporal difference in the act of translating ideas into written text (as opposed to verbal communication of ideas), allows for more opportunity for evaluation and revision, processes that require the selective activation of the DAN.

Psychological Applications: Expressive Writing

Given that writing has specific implications for the functional organization of opposing networks of cognitive control, it is next important to analyze these findings for further psychological implications of writing. As briefly discussed in the introduction, writing has long been associated with psychopathologies. However, the directionality in this relationship is more difficult to parse out. Do people with predispositions to psychopathology gravitate towards writing for its soothing effects on the mind? Or does the habit of writing itself encourage negative cognitive habits, such as excess rumination? Although these questions are beyond the scope of this paper, I will examine expressive writing as a therapeutic treatment in order to help elucidate the relationship between psychopathology and writing.

Expressive writing—defined as writing about emotional, often negative personal experiences—has been researched as a psychological intervention since the 1980's (Pennebaker 1997). This type of emotional writing has been associated with strengthened immune function, self-reported benefits to mood and stress, and positive professional behavioral outcomes, such as reemployment after a job loss (Pennebaker 1997). In light of these findings Pennebaker proposes two possible explanations: First, that self-disclosure in expressive writing might reduce inhibition of (not talking about) important psychological experiences, and second, that expressive writing engages cognitive processes to cohere emotional experiences.

The neurological findings regardings writing in general can shed light onto the mechanisms underlying these hypotheses. The inhibition described by Pennebaker is based on the theory that repressing psychological expression causes stress, which in turn causes negative psychological and physiological outcomes. I propose that from a neurological standpoint, this inhibition of the expression of emotional experiences can be understood as a disruption in the balance between competing brain networks, namely between the DMN and the DAN. Patients with PTSD were shown to have decreased overall interconnectivity in the DMN, specifically in prefrontal regions (Akiki et al. 2018). Specifically, reduced activation in the vmPFC was associated with fear inhibition in patients with PTSD (Kredlow et al. 2021). Given that a subset of PTSD symptoms involves repression of fear memories (Kredlow et al. 2021), and that the DMN is involved in the spontaneous generation of episodic memory, dysregulation of the DMN might facilitate this repression. Therefore, I argue that the practice of finding the optimal balance between the DAN and the DMN—and particularly the attenuation of the DAN to allow for more spontaneous generation—serves to release psychological inhibitions. As I outlined above, the attenuation of top-down attentional control can reallocate cognitive resources to other executive control regions, allowing for more access to spontaneous self-generated ideas, and even emotional processing. Additionally, as shown in the stronger deactivation of the DAN in expert writers, writing practice can facilitate the modulation of these networks. This modulation may even become automatized via the basal ganglia. Thus, expressive writing might have long term benefits for inhibition of memories as a result of the continued modulation between these two opposing networks.

This deactivation of the DAN has also been associated with positive psychological traits. For example, Chrysikou et al. (2013) found that inhibitory transcranial direct current simulation of left prefrontal regions showed associations with cognitive flexibility. This finding supports the suggestion that the deactivation of the dlPFC facilitates creative thinking. Additionally, cognitive flexibility has previously been associated with the dlPFC, and has been shown to be impaired in a number of psychopathologies (Whiting et al. 2017). Taken together, these findings suggest that deactivation of the DAN might be a possible mechanism by which writing facilitates positive psychological traits, such as cognitive flexibility, that can improve incidences of psychopathologies.

To Pennebaker's second point, that the cognitive processing involved in expressive writing facilitates positive psychological outcomes, I return to Flower and Hayes (1981). According to their cognitive process model of writing, the growth aspect of writing occurs as a bidirectional relationship between the text and one's goals. The consolidation of ideas to generate a text can also influence the organization of goals, and those goals can in turn influence the rest of the written text. This simultaneous growth of both the written text and one's goals is undoubtedly a complex cognitive process that requires interactions between complex neural systems. As displayed during Liu et al. (2015)'s revision stage, increases in activation of the DAN were associated with evaluation, planning, and organizing tasks. Thus, the cognitive processing alluded to by Pennebaker and described in more detail by Flower and Hayes can be understood, at least in part, as the prioritization of the DAN and its top-down attentional control. Importantly for the present discussion of expressive writing, a transcranial direct current stimulation study found that the dlPFC is involved in the regulation and control of valence of emotional information (Nejati et al. 2021). It is the planning and organizational control exerted by the dlPFC/DAN that can facilitate the cognitive changes that improve emotional experiences.

While neither of these hypotheses can be entirely explained by neuroscientific findings, the involvement of both the DMN in inhibition and the DAN in cognitive processing suggest that benefits of expressive writing can be understood as a result of continually finding the optimal balance between these two networks. Prioritization of the DMN might facilitate access to inhibited memories, but the subsequent activation of the DAN might allow those memories to be evaluated and organized. At this point, there is strong evidence to support the idea that psychological interventions, such as cognitive behavioral therapy, have lasting effects on the function and structure of the brain as a result of plastic changes to the frontal, cingulate, and limbic cortices (Collerton 2013). Further research is required to make similar conclusions about writing as a psychological intervention, but given neuroimaging findings related to expert writers and the growing body of evidence for the health benefits of expressive writing, I argue that these further investigations are not only warranted, but necessary.

Conclusion

Writing is an incredibly diverse and complex behavioral and cognitive process. This investigation into writing from a neuroscientific perspective sought to unify three distinct scholarly discussions of writing: cognitive theories, neuroscientific explorations of writing as a creative act, and expressive writing as a psychological intervention. In doing so, I argue that writing, even in its diverse forms, is characterized by a continual modulation between the DMN and the DAN in an attempt to find the moment-to-moment optimal balance between the two. This optimal balance is influenced by the requirements of the writing task, the development of one's goals and subgoals, the environment in which one writes, and the emotional state of the writer, just to name a few. That is to say, writing requires the integration of diverse information to inform its prioritization of either the DMN or the DAN. With respect to expressive writing, this network balance may be crucial in both accessing inhibited emotions or memories, and the evaluation and organization of that information.

Overall, further research is needed in this field of study to make more specific conclusions about the writing brain. Currently neuroimaging studies focus on writing exclusively as an example of creative thinking, but as I demonstrate with the optimization of the DMN and DAN, this body of research can be expanded to other aspects of writing, such as expressive writing or writing to learn. Further research into writing as a therapeutic intervention will not only expand knowledge on its efficacy and mechanisms, but could also reveal potential neural targets for other types of treatment. Additionally, in regard to the diversity of writing projects, future research should include a variety of writing tasks, expanding beyond typically defined "creative writing." While research into poetry, fiction, etc is valuable in understanding more imaginative and emotional processes involved in writing, studies on technical, evidence-based writing could reveal if more logical material requires distinct neural processes. Comparison between experts and novices should also be expanded to include a wider range of expertise. A sample of critically acclaimed professional writers, as opposed to writing students (Liu et al. 2015), could further reveal the effects of innovation and mastery of the literary craft. Additionally, research could expand to writers across a wide age span, or longitudinal analysis to examine the development of a writer over time. Lastly, as is the case with all neuropsychological research, this body of research would be made stronger with the inclusion of a more diverse sample across gender, ethnicity, socioeconomic status, literary background, etc.

Despite these limitations and the need for further research, my proposed model is the first to bridge the gap between neuroimaging research on writing and the psychological intervention of expressive writing. In doing so, I centered my focus on the optimization between the DMN and the DAN, and how this optimization facilitates the balance between spontaneous self-generated thinking and attention-driven organization. When extended to expressive writing, this optimized functional balance can promote positive psychological traits, such as cognitive flexibility.

To end my discussion of the writing brain, I turn to another quote by a venerated writer: Joan Didion. "I write entirely to find out what I'm thinking, what I'm looking at, what I see and what it means. What I want and what I fear.” Viewing this quote through the lens of my neural model, Didion’s words refer to both the spontaneous generation of the DMN and the attentional control of the DAN. Accessing her wants and fears can be facilitated by the prioritization of the DMN and its role in self-generated autobiographical recall. Yet, making sense of her thoughts and forming meaning around them likely requires the attention-driven planning provided by the DAN. The balance between these two contrasting ways of thinking not only allows writers to generate a written text, but to form meaning around parts of the world and themselves that they might not be able to access without writing.

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