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Research article

The Origins of a Spontaneous Thought: EEG Correlates and Thinkers' Source Attributions

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Abstract: Spontaneous thoughts can arise from past memories, future tasks, and environmental cues. We developed a paradigm to investigate the stream of consciousness leading to spontaneous thoughts. While performing a concentration exercise (9 min) requiring one to focus only on one's breathing, subjects observed spontaneous thoughts and counted the number of cognitions/percepts ('links') that they believed led to each spontaneous thought. In Studies 1–3, subjects reported less than 2 links per thought, over 80% of thoughts were attributed to a known cause, and roughly half of the thoughts were attributed to something outside the current environment. In Study 4, we examined the neural correlates of spontaneous thoughts triggered by external stimuli or internal, stimulus-independent factors (e.g., memories). Continuous EEG was recorded from seven active electrode sites (Fz, Cz, Pz, F3, F4, P3, and P4) as subjects indicated experiencing a thought. Subjects indicated whether their thoughts arose from internal (e.g., memories) or external (sights, sounds, smells, and bodily sensations) factors. To examine the neural correlates of each individually-reported thought, EEG was examined in short time scales (< 1 s) preceding each button press. Increased alpha correlation was observed for internal thoughts compared to a baseline condition (eyes-opened resting). In addition, increased alpha correlation in the parietal region was observed for internal compared to external thoughts. These findings are in line with previous research implicating distinct brain networks for internal and external awareness. We discuss the implications and potential future applications of this new approach for investigating the stream of consciousness.

Keywords: spontaneous thought; task unrelated thought; mind wandering; stream of consciousness; consciousness

When a man thinks on anything whatever, his next thought after is not altogether so casual as it seems to be. Not every thought to every thought succeeds indifferently.

—Thomas Hobbes, Leviathan (1651, p.8)

1. Introduction

There is an amusing anecdote in the annals of psychology of a troubled young man asking Sigmund Freud about the meaning of a strange and recurring thought. The young man told Freud that the same random thought kept entering his mind, even when the thought was unrelated to the current environment. A staunch believer in *psychic determinism*, Freud explained to the young man how this undesired thought was in fact determined by important causes. According to Freud, such out-of-the-blue and involuntary, "spontaneous thoughts" result from a causal chain of thoughts that arise from deep, unconscious motivations [1]. One is often conscious of only the last series of thoughts forming such a causal chain. The anecdote ends with Freud explaining to the young man how the recurrent thought resulted from a chain of thoughts triggered by a troubling situation, namely, that the young man had become an unexpectant father [2]. In this case, the recurring thought seemed unrelated to the current environment.

It will never be known by modern science whether Freud's conclusion about the origin of this young man's recurring thought was in fact correct. However, few today would argue against the doctrine of psychic determinism. Recent research has revealed that, as indeterminate as spontaneous cognitions appear to be, they are likely to arise from determined, causal processes in the brain [3,4], in accordance with Freud's general conclusions. For example, recent investigations have revealed that spontaneous thoughts can be activated unintentionally by the anticipation of future tasks [5], concerns about past events [6], the evaluation of past events [7], the experience of a negative event [8–10], and stimuli in the present environment [11,12]. More generally, many conscious thoughts appear to be determined by concerns and sophisticated calculations that are themselves unconscious [13–15], as evident in the case of the *unconscious inference* [16].

These conclusions are also supported by classic research on spontaneous thoughts, mind wandering, and task-unrelated thought (TUT; [17,18]). (See [19] for a discussion on why these terms, although often used interchangeably, do not necessarily reflect the same processes.) For example, researchers have indexed the nature of TUTs (e.g., [17,20]) and the conditions under which TUTs arise. In one experiment, increasing the cognitive demands of a current task (a signal detection task) decreased TUTs [17]. Similarly, Giambra and Grodsky [21] found that TUTs arise less often when subjects are highly engaged in a task (e.g., when reading something of high interest) than when engagement is low (e.g., when reading something of low interest). A second experiment in Antrobus et al. [17] revealed that reward/punishment contingencies can influence the probability of TUTs. (See Giambra [22] for a treatment of how the occurrence of TUTs varies as a function of factors such as time of day, aging, and psychopathology.) There is evidence that there are stable individual differences in the rate of TUTs across different task domains (e.g., vigilance tasks versus semantic tasks [23]). For related, recent treatments of the difference between internally-based and externally-based task distractions, see Clapp and Gazzaley [24]. (For a review regarding TUTs and their relation to executive models of attention, see Smallwood and Schooler [25].)

Despite the often hidden origins of spontaneous thoughts—origins that are detected often only through scientific methods such as electroencephalographic activity (EEG) and other forms of neuroimaging [3,4,26]—most people have had the experience of themselves attributing a spontaneous thought to one or more events, just as Freud did in our anecdote. From this observation, it is reasonable to ask what may be the average number of cues or 'links' that one observes leads to a spontaneous thought. (Note that we are not referring to subjects' general attribution processes during the occurrence of thoughts [27], but rather to the thought ancestry—the number of cognitions or percepts preceding a spontaneous thought that seem to give rise to the thought.) With today's introspection-based methods (e.g., [10,28,29]), it is feasible to address this question about the number of thought ancestors that people normally attribute to their task-irrelevant, out-of-the-blue cognitions. As outlined below, ascertaining this datum is a noteworthy empirical development that begins to shed light on the understudied stream of consciousness (cf., [17]), regardless of whether a thinker's inferences about the thought ancestry of a given spontaneous cognition are accurate. Regarding the nature of the "stream of consciousness," William James [30], who coined the felicitous term, concludes, "[it] does not appear to itself chopped up in bits. Such words as 'chain' or 'train' do not describe it fitly as it presents itself in the first instance. It is nothing jointed; it flows. A 'river' or 'stream' are the metaphors by which it is most naturally described" (p.239). (It is important to distinguish our usage of the term "stream of consciousness," which is used in psychological research [e.g., 17–20], from that used in narrative theory.)

In synthesis, the primary aim of the current empirical project was to investigate the thinker's interpretations of the stream of consciousness leading to a spontaneous conscious thought. Importantly, the primary aim of this research project was, not to examine the nature of each spontaneous thought, but rather only to illuminate subjects' judgments about the nature of the stream of consciousness that lead to each spontaneous thought.

To this end, in Studies 1–3, we used a new paradigm to investigate the stream of consciousness leading to spontaneous conscious thoughts. As outlined below, subjects observed spontaneous thoughts and counted the number of cognitions/percepts ('links') that they believed led to each spontaneous thought. Examining the subjectively-experienced determinants of spontaneous thought is additionally the first step in elucidating the cognitive and neural precursors of spontaneous thoughts (see further discussion below, in Study 4). In addition, assessing how subjects apprehend the thought ancestry of a spontaneous cognition (i.e., the number of cues, or 'links,' in the causal chain believed to lead to a spontaneous thought) is relevant to several lines of research, including previous findings regarding involuntary autobiographical memories [11], the facile manner in which people make sense of random or inexplicable events [31], people's need to understand the world and their experience ('need for cognition,' [32]), the capacity limitations of conscious processing [33–35], and the view that conscious thoughts are usually evoked by environmental stimuli and seldom stem from long, complicated chains of thought [15]. In addition, subjects' attributions may reflect the quantity of information that can be held in working memory ("the magical number seven"; [36]) and perceived during the act of 'subitizing' [33,37].

In the literature, there are introspection-based studies in which subjects detect spontaneous thoughts and subsequently provide a report about the nature of each of these thoughts (see reviews in Smallwood and Schooler [25] and Raz and Lifshitz [38]). However, to our knowledge, there is no study in which subjects provide, for each thought, the number of cognitions/percepts ('links') that they believed led to each spontaneous thought.

Another aspect of spontaneous thoughts is whether the thoughts are triggered by stimuli in the environment or by processes that are unrelated to stimuli in the present environment (as was the case in Freud's observation). Research has demonstrated that people can attribute their spontaneous thoughts to either cues in the environment or to internal cognitive processes [39]. Using our new paradigm, we also investigated this phenomenon in Studies 2 and 3. Building on these studies, in Study 4, we examined the neural correlates of spontaneous thoughts triggered by external stimuli or internal, stimulus-independent factors (e.g., memories and wandering thoughts). By providing more objective data about the occurrence of spontaneous thoughts, whether these thoughts are triggered by internal stimuli or external stimuli, Study 4 provides additional evidence that, for Studies 1 through 3, subjects are not confabulating about the occurrence of these mental events, which are the focus of our empirical investigation. Previous research provides some evidence that subjects, when introspecting about their mental states and reporting about these states, are not confabulating (see [40–43]). However, for us to be more confident about the nature of our introspective data (e.g., that concerning internal versus external thoughts, defined below), we strove to have objective, neuroimaging-based data that stems from the behavioral paradigm presented in Studies 1 through 3.

2. Study 1

Regarding our first aim, although examining the perceived (or inferred) thought ancestry of spontaneous thoughts is important for several reasons, to date, there is no method for investigating the nature of these thought sequences systematically. To this end, we developed a quantitative paradigm that begins to illuminate the nature of these sequences in the stream of consciousness. Specifically, we examined the number of thoughts or 'links' that subjects perceive as having led to a given spontaneous thought. In our new paradigm, subjects jot down an "X" on paper whenever they experience a spontaneous thought. Immediately after noting the instance of a spontaneous cognition, subjects indicate the number of links that they believed led to the cognition. It is important to emphasize that, in this quantitative paradigm, the dependent measure is much less variable than that observed in thought sampling studies: This paradigm is designed to examine, not the contents of the thoughts, but the number of links (i.e., thought precursors) that subjects attribute to one spontaneous thought.

In the paradigm, subjects perform this monitoring task while performing a concentration task in which they must focus on their breathing. Previous research [5] reveals that, in this kind of task, task-unrelated thoughts are likely to occur. In addition, we had subjects perform this task, rather than simply "do nothing," because we wanted our experimental arrangement to resemble that which occurs in everyday life, where spontaneous cognitions are usually experienced while one is doing something. Another motivation for having subjects perform this task was to reduce random error by having all subjects be in a similar cognitive set. In synthesis, when designing the study, we strove to have subjects perform a mental task that would (a) have all participants be in a similar mental state, (b) diminish inter-individual variability and random error, (c) diminish the likelihood of intentional daydreaming, and (d) not yield floor effects regarding the occurrence of spontaneous thoughts.

2.1. Method

2.1.1. Subjects

San Francisco State University students (n = 30) were run as a group in a single session and participated for class credit. The involvement of human subjects in this study and in the subsequent studies was approved by the Institutional Review Board at San Francisco State University.

2.1.2. Procedures

Each subject received a 3-page packet that included instructions and a blank piece of paper to indicate the occurrence of thoughts during the concentration task. The instructions for the concentration task read:

During the concentration task, it is common for people to be distracted by thoughts, feelings, and bodily sensations. Our thoughts can be caused by other thoughts or things in the environment. Sometimes, there is one link that leads from the thought or thing in the environment to the thought we experience. Other times, there are multiple links leading from the initial thought or thing in the environment, to other thoughts, and then to the thought we experience. And other times, there does not appear to be any link. To summarize, there can be none, one, or multiple links that lead to a thought.

When you have a thought, write an 'X.' Think about what caused your thought, and next to the 'X' write the number of links that led from the initial thought or thing in the environment to your thought.

Subjects then performed the concentration task while listening to a 9-min narrative audiotape [44] about meditation and focused breathing. The audiotape included many intermittent pauses of silence. Because we were not interested in examining subjects' thoughts as a function of the environment but rather observing them in a single setting, the audiotape, which had successfully been used in a previous study of spontaneous thoughts [5], was chosen to provide a standard environment for subjects under which thought introspections could be observed. Subjects were allowed to perform the link-counting task after experiencing thoughts at any point during the narrative, thus allowing subjects' thoughts to be influenced by the audiotape recording, the surrounding environment, and subjects' own internal mental activity. Subjects were not required, nor instructed by us, to close their eyes. Our aim was for subjects to be able to apprehend the surrounding environment and jot down information.

So as to decrease experimental demand and not influence the number of links subjects reported for any one thought, instructions were carefully worded as "none, one, or multiple links" so subjects could indicate the specific number of links per thought they observed to be correct. Upon completion of the 9-min audiotape, subjects completed a funneled debriefing consisting of the questions 'Do you have any ideas regarding the purpose of this exercise? Circle yes or no' and 'If you circled 'yes,' what do you believe to be the purpose of this exercise? Please explain in a few sentences.' No data were excluded from analysis on the basis of the debriefing data.

2.2. Data Analysis

Two subjects were excluded from all data analyses for illegible handwriting or failure to follow instructions. Additionally, three subjects did not indicate the occurrence of any thought and were excluded from the analyses about the links. Although no subject indicated a failure to understand the task, several subjects (n = 8) wrote out their thoughts instead of indicating the occurrence of their thoughts and the introspected number of links. As it was impossible to determine exactly what subjects might have introspected regarding the causes of these thoughts, and since we did not want to introduce any experimenter bias by interpreting what subjects wrote, the data from these subjects were excluded from all link count analyses (but see discussion of these data in Results, Study 3). Therefore, all subsequent analyses and results include only data directly reported by subjects and data that reflect subjects' own introspections.

2.3. Results and Discussion

All the descriptive statistics are presented in Table 1. The mean number of links per thought was less than 2. The average number of reported thoughts per subject was 9.18; however, there was a large variance among subjects (SE = 1.95). The mode number of links per thought was 1, and the majority of thoughts (84.9%) was reported to have one or more links. Interestingly, 15.9% of the thoughts were jotted down without any indication of the number of links, suggesting that subjects were not able to introspect the causes of some of their thoughts.

3. Study 2

To capture in a paradigm the kind of phenomenon noted by Freud, it is important to demonstrate that, in such a paradigm, the spontaneous thoughts detected are not merely cognitions triggered by the current environment. Previous findings show that subjects attribute spontaneous cognitions to the present environment [11] and such cognitions, like actions, reflect an environmental dependency to some extent [13,45–48]. Thus, in Study 2, we replicated Study 1 and also ascertained what proportion of spontaneous thoughts were triggered by processes unrelated to the current environment. When founding this paradigm, it was important to document that not all thoughts were triggered by the external environment.

3.1. Method

3.1.1. Subjects

San Francisco State University students (n = 74) were run as a group in a single session and participated for class credit.

3.1.2. Procedures

The subjects underwent the exact procedures of Study 1, but were additionally verbally instructed to write an 'E' next to every thought that was believed to be a result of a stimulus in the immediate external environment. Again, no data were excluded from analysis on the basis of the debriefing data.

3.2. Data Analysis

The data from three subjects were excluded from all analyses due to illegible handwriting or failure to follow directions. Four additional subjects did not indicate experiencing any thoughts, and two additional subjects wrote out their thoughts without clearly indicating what number of links, if any, they attributed to their thoughts. These subjects were therefore excluded from all link count analyses.

Due to the distinct components of internally-directed and externally-directed attention (e.g., [49]), thoughts indicated to be a result of a stimulus in the immediate, external environment were analyzed separately. These thoughts with a source in the external environment ("external thoughts," for short) were further examined on the basis of whether or not additional links were reported. While in Study 1 subjects reported 0 links to a thought if they could not introspect any causes leading up to their thought, for this study it was clear that for thoughts indicated to have resulted from something in the environment, subjects had also introspected, to a degree, the cause (e.g., a stimulus in the present environment), regardless of any additional links introspected to constitute the thought's ancestry. In order not to confound these data or to over interpret subjects' introspections, for the reported external thoughts, we excluded external thoughts with no additional reported links (XE) from link count analyses and examined the remaining link counts out of all reported external thoughts as well as just out of external thoughts reported with an additional number of links (i.e., 1 or more).

3.3. Results and Discussion

As is revealed in Table 1 and consistent with the findings from Study 1, the mean number of links per thought was less than two for both internal and external thoughts. Out of all thoughts (internal or external), the majority (80%) was reported to have one or more identifiable causes leading up to the occurrence of the thought. Interestingly, as in Study 1, a minority (20%) of the thoughts were jotted down without any indication of the cause of the thoughts.

In addition, roughly 53% (*SE* = 3.30%) of the spontaneous cognitions were attributed by subjects to the current environment. The average number of thoughts attributed to the current environment was not significantly different from the average number of thoughts attributed to internal sources, $t(64) = 1.06$, $p = 0.294$, and there was a significant, positive correlation between the average number of internal and external thoughts, $r = 0.34$, $p = 0.006$. Similar to Study 1, the average number of reported thoughts per subject was 9.28; however, again there was a large variance among subjects (*SE* = 0.81). Importantly, not all thoughts were triggered by environmental stimuli.

Table 1. Summary of Results for Studies 1–3.

	n	Mean	*SEM*	Range	
				Minimum	Maximum
Study 1					
Number of Thoughts per Subject	28	9.18	1.95	0	47
Number of Thoughts with Links per Subject	17	12.18	2.90	2	47
Total Number of Links per Subject	17	18.88	4.59	0	65
Average Number of Links per Thought per Subject	17	1.58	0.23	0	4.33
Study 2					
Number of Thoughts per Subject	71	9.28	0.81	0	34
Number of Thoughts with Links per Subject	65	9.94	0.82	1	34
Total Number of External Thoughts per Subject	65	5.28	0.54	0	20
Proportion of External Thoughts per Subject	65	0.53	0.03	0	1
Total Number of External Thoughts without XE* per Subject	65	2.11	0.44	0	15
Proportion of External Thoughts without XE* per Subject	65	0.19	0.04	0	1
Total Number of Internal Thoughts per Subject	65	4.66	0.47	0	15
Proportion of Internal Thoughts per Subject	65	0.47	0.03	0	1
Total Number of Links of External Thoughts per Subject	29	7.72	1.30	1	29
Average Number of Links per External Thought per Subject	29	1.06	0.10	0.29	2.57
Average Number of Links per External Thought without XE* per Subject	29	1.72	0.11	1	3
Total Number of Links of Internal Thought per Subject	58	5.09	0.81	0	27
Average Number of Links per Internal Thought per Subject	58	1.02	0.13	0	5

Study 3					
Number of Thoughts per Subject	67	11.45	0.93	0	35
Number of Thoughts with Links per Subject	65	11.71	0.93	2	35
Total Number of External Thoughts per Subject	65	5.71	0.61	0	28
Proportion of External Thoughts per Subject	65	0.49	0.03	0	1
Total Number of External Thoughts without XE* per Subject	65	2.94	0.51	0	25
Proportion of External Thoughts without XE* per Subject	65	0.26	0.03	0	1
Total Number of Internal Thoughts per Subject	65	6.00	0.56	0	23
Proportion of Internal Thoughts per Subject	65	0.51	0.03	0	1
Total Number of Links of External Thoughts per Subject	45	6.78	0.95	0	31
Average Number of Links per External Thought per Subject	42	1.23	0.11	0.13	3
Average Number of Links per External Thought without XE* per Subject	42	1.75	0.10	1	3
Total Number of Links of Internal Thought per Subject	63	8.49	1.27	0	59
Average Number of Links per Internal Thought per Subject	63	1.26	0.11	0	3

*XE = External thought with no additional reported link.

4. Study 3

In Study 3, we took the opportunity to replicate Study 2 with a different sample of subjects.

4.1. Method

4.1.1. Subjects

San Francisco State University students (*n* = 73) were run as a group in a single session and participated for class credit.

4.1.2. Procedures

The subjects underwent the exact procedures of Study 2. Again, no data were excluded from analysis on the basis of the debriefing data

4.2. Data Analysis

The analysis procedures of Study 2 were applied to the data in Study 3. The data from six participants were excluded from all analyses due to illegible handwriting or failure to follow directions. One additional participant did not indicate experiencing any thoughts and another additional participant wrote out his or her thoughts without clearly indicating what number of links, if any, the participant attributed to his or her thoughts. These participants were therefore excluded from all link count analyses, leaving 65 participants for link analysis.

4.3. Results and General Discussion

The findings resembled those of Study 2 (Table 1). As in Study 2, the proportions of internal thoughts (M = 0.51) and external thoughts (M = 0.49) were comparable, $p > 0.60$. Importantly, this replication provides additional evidence that, in our paradigm, not all cognitions are attributed to the external environment.

It is important to note that, in our paradigm, subjects do not jot down the content of their thoughts. Such information falls outside the purview of the present version of our paradigm. However, a related study sheds some light on the potential nature of these thoughts. A study by Morsella et al. [5] examined spontaneous thoughts as a function of pending, future tasks. They found that tasks that may benefit from forethought systematically triggered prospective, task-related cognitions. In that study, subjects self-reported instances of spontaneous thoughts and, unlike in our study, wrote out the content of their thoughts while listening to the same portion of the audio-tape [44] used in the current studies. Regarding the potential contents of the spontaneous thoughts in the present study, it is important to point out that, in the control condition of Morsella et al. [5], the content of stimulus-oriented thoughts was frequently related to the audio-tape (e.g., “sounds like the speakers in a yoga meditation class”) or to the surrounding people or noises (e.g., “people shuffling in their seats”). Other thoughts frequently consisted of future-related thoughts (e.g., “thought about work tonight”) or were unspecified in regard to time (e.g., “my cat”). Thoughts also frequently consisted of body or emotion-related content (e.g., “I am really hungry”). Because subjects were listening to the same audio-tape in a similar environment, and because the control condition of Morsella et al. [5] was designed to not systematically influence subjects’ thoughts in any particular manner, the content and variability of subjects’ thoughts were likely similar to what subjects experienced in our current studies.

Regarding thought content, some additional data were obtained in Study 1, in which eight subjects in Study 1 (who constituted 27% of the subjects of that study) wrote out their thoughts and did not clearly indicate a number of links per thought. We conducted a separate content analysis on these remaining eight subjects to determine any patterns between these data and the results reported for Study 1. Upon inspection of these subjects’ written thoughts, it was observed that the majority of thoughts ($n = 28$) pertained to direct observations of the environment and that each thought could be considered to have one link. Five thoughts from various subjects were written out with their preceding determinants also listed, allowing us to infer the most likely number of links subjects would have reported per thought: Two of these thoughts had two links, and the other three thoughts had one link. Lastly, ten additional thoughts were written but a specific number of links could not be determined based on the content. The written thought content from these subjects, when interpreted in a systematic manner by the researchers, yields a minimal number of links per thought similar to the findings observed in Study 1. As these are not introspective data and are based on the researchers’ interpretations of subjects’ written thought content, these findings should be interpreted conservatively and are provided only as an addition to the results detailed in Study 1 and to the observations from Morsella et al. [5].

5. Study 4: Neural Correlates of Spontaneous Thought

As mentioned above, spontaneous thought and its neural correlates have commonly been studied in the larger context of mind wandering, stimulus-independent thought, and undirected thought. (We should specify that “stimulus-independent thought” refers to thoughts that are independent of the stimuli composing the present, physical environment.) Research has largely implicated the default mode network as a neural correlate of mind wandering and spontaneous thought production [19,40,50,51]. The default mode network is a brain network that is typically activated during conditions in which there is no external task to perform. Its regions include the posterior cingulate cortex, the medial prefrontal cortex, the precuneus, and the inferior parietal and lateral temporal cortex [51,52]. Additional brain regions linked to spontaneous thought production include the medial temporal lobe structures and rostrolateral prefrontal cortex [19]. Other studies have suggested an involvement of both the default mode network and executive network regions (e.g., anterior cingulate cortex and dorsolateral prefrontal cortex) in the production of mind wandering [53,54] (however, see [41], for an argument against this perspective). Electrophysiology studies have revealed several neural correlates of mind wandering, including reduced amplitude in the P300 ERP component [55], enhanced alpha activity [56] (but see Braboszcz & Delorme [57], for a case in which alpha power decreased during mind wandering), and the ratio between both (a) beta and alpha power, and (b) beta and the sum of alpha and theta power [58].

In general, the neural correlates of spontaneous thought have been studied in terms of the mental processes that occur during awake, resting conditions [19]. The employment of this research approach has been based on 1) the observation that during rest or other conditions of low external demands, individuals often experience spontaneous thoughts, and 2) the assumption that the brain activations observed at rest reflect the occurrence of spontaneous cognition [19]. Little research has examined the neural correlates of spontaneous thoughts on a trial-by-trial basis. In addition, little research has examined spontaneous thought processes within a time range small enough (e.g., milliseconds) that could allow investigators to examine the neural processes of each thought in light of concurrent self-report. One exception is a series of studies by Lehmann and colleagues, in which the investigators examined the momentary brain electric field maps that immediately preceded (prompted) reports of recall of spontaneous, conscious experiences [59]. The investigators observed significantly different microstates associated with abstract thought compared to mental imagery.

In Study 4, we build on this literature by examining the neural correlates of spontaneous thought by recording continuous EEG while subjects experienced and reported spontaneous thoughts on a trial-by-trial basis. As mentioned above, by providing objective data about the occurrence of spontaneous thoughts that are triggered by internal stimuli or external stimuli, Study 4 provides additional, corroboratory evidence that, in our paradigm, subjects are not confabulating about the occurrence of these thoughts.

Building on Studies 2 and 3, for each spontaneous thought, we had subjects report whether the thought was triggered by an internal or external source. We examined EEG activity on a time scale small enough (< 1 s) to home in on the neural correlates of each reported spontaneous thought. The focus of analysis compared the neural correlates of spontaneous thoughts triggered by stimulus-independent cognitions (internal thoughts) or by stimuli in the present, external environment (external thoughts). As a baseline comparison, we used a 2-min eyes-opened resting condition recorded after task completion.

Our focus on an internal versus external distinction was motivated by several factors. First, it is important to demonstrate in our paradigm that all spontaneous thoughts are not simply triggered by the external environment and that many are task- and stimulus-independent thoughts. Second, the object of investigation was motivated by the robust findings observed in Studies 2 and 3, in which subjects attributed approximately half of their thoughts to stimuli in the external environment. Last, the focus was motivated by the observation that, despite much previous research demonstrating that subjects experience both internally- and externally-triggered thoughts [39,60], and the large amount of literature that points to distinct processes for internal and external awareness (e.g., [49]) and attention (e.g., [61]), little research has investigated the neural correlates of internally- and externally-triggered thoughts on a time scale comparable to that used in the current study.

In addition, we focused our EEG analysis on alpha band (8–13 Hz) activity. Much previous research has demonstrated the role of alpha (8–13 Hz) activity in regulating externally and internally-directed attentional mechanisms during both directed thought processing and mind wandering. For example, increased alpha power has been observed during internally-directed attention tasks compared to externally-directed attention tasks [62]. In addition, Sauseng et al. [63] examined alpha coherence during a visual working memory task and observed increased fronto-parietal alpha coherence under increased task demands. More generally, in a review on attention and oscillatory patterns, Mathewson et al. [64] described how alpha oscillations play a role in inhibitory control and revealed that the phase of alpha oscillations may influence the extent to which stimuli are preferentially processed. Alpha activity has also been associated with resting state and spontaneous thought processes (e.g., [65,66]). For example, in a simultaneous EEG and fMRI study, Mantini et al. [66] observed alpha power to be positively correlated with the default mode network. Given this previous research, we predicted that alpha activity should reflect attentional processes underlying internally- and externally-triggered spontaneous thoughts on a trial-by-trial basis. In our analysis, we used the correlation coefficient measure (a measure that is similar to coherence, [67,68]) to examine within the alpha band the functional connectivity of the brain regions underlying the electrodes from which we recorded.

5.1. Method

5.1.1. Subjects

San Francisco State University students (n = 57) were run individually and participated for class credit. All subjects provided written consent, were right-handed, and reported normal health and no neurological disorders. Data from six subjects were excluded due to noisy data quality. In addition, one subject reported being left-handed, one subject requested to stop the experiment early; 12 subjects failed to report a sufficient number of trials for each condition; and one person was determined to be an outlier after being included in an initial analysis. The data from these 21 subjects were thus excluded from all analyses, leaving data from 36 subjects (17 female, M_{age} = 24.25 years, SD_{age} = 3.46) for analysis.

5.1.2. Procedures

All instructions were presented on a Dell Optiplex GX620 computer using SuperLab 4.0 [69]. The experimenter read aloud all instructions and ensured subjects understood the task. The experimenter explained that thoughts can be caused by other thoughts and things in the environment. Following the descriptions of Vanhaudenhuyse et al. [49], internal thoughts were described as including “wandering thoughts or memories” and external thoughts were described as arising from “sights, sounds, smells, or bodily sensations.”

Subjects were instructed at the start of each trial to (a) clear their thoughts so that they were not focusing on anything in particular in their mind or in the external environment, and (b) press the spacebar to begin the trial. Subjects were instructed to try to keep their thoughts cleared as best as they could for a period of time (10 s) until a cue (+) appeared on the screen for 500 ms. Subjects were instructed to press the spacebar when they experienced a thought any time after the cue disappeared. Subjects reported only one thought per trial. Upon pressing the spacebar to indicate a thought, subjects indicated by keyboard the number of ‘links’ (i.e., the number of other thoughts or percepts in the environment that they introspected per thought) and whether they attributed their thought to an internal (key ‘i’) or external (key ‘e’) source.

Each subject completed a 2-min eyes-opened resting state baseline condition at the start of the recording session. After receiving the task instructions, subjects completed a practice trial and 24 critical trials. Subjects completed a second 2-min eyes-opened resting state baseline condition upon completion of the trials (used here in the analysis as the eyes-opened post-task baseline comparison; EOPB), followed by a 2-min eyes-opened focused baseline condition in which subjects were instructed to focus on their breathing and count their breath cycles (inhale/exhale) up to ten (following procedures of Braboszcz and Delorme [57]). Lastly, subjects performed an eyes-closed resting state baseline condition for one minute. Upon completion of the recording session, subjects completed a funneled debriefing questionnaire (based on procedures of Bargh and Chartrand [70]) that consisted of the following questions. 1) What do you think the purpose of the experiment was? 2) What topic do you think we are trying to study? 3) What were you trying to do during the experiment? Did you have any goal or strategy? 4) On a scale of −3 to +3, with −3 being 'not very easy at all' and +3 being 'extremely easy,' how easy was it for you to clear your head at the start of each trial? Please mark an 'X' on the scale. 5) On a scale of −3 to +3, with −3 being 'not very easy at all' and +3 being 'extremely easy,' how easy was it for you to experience a spontaneous thought when instructed? Please mark an 'X' on the scale. 6) On a scale of −3 to +3, with -3 being 'not very easy at all' and +3 being 'extremely easy,' how easy was it for you to determine whether your thought was internal/external? Please mark an 'X' on the scale. 7) Were there any conditions that made the task more difficult? Please describe.

5.2. EEG Recording and Analysis

Continuous EEG was recorded from seven tin electrodes (Fz, Cz, Pz, F3, F4, P3, and P4) pre-positioned in an electrode cap according to the International 10–20 Electrode Placement System and was referenced to linked mastoids. EEG was amplified using the BIOPAC MP150 data acquisition system and digitally recorded using Acqknowledge 4.0 software. Eye artifacts were recorded from two electrodes: one electrode placed horizontally at the outer canthus of the left eye and a second electrode placed vertically below the inner canthus of the left eye. All electrode impedances were kept below 20 kΩ. Data were sampled at 250 Hz and filtered online with a .01 Hz to 30 Hz bandpass. The waveform was bandpass filtered offline such that the alpha band was 8 Hz to 13 Hz. For analysis, we extracted from each trial one 500-ms epoch that preceded the button press by 400 ms (i.e., each epoch began 900 ms before the button press). This time period was used for analysis as a means to exclude any EEG signals resulting from the motor activity of the button press, as well as to home in on the time course of the neural processes likely associated with the experience of a spontaneous thought. (Further details regarding the selection of these epochs can be found at the end of the Results section.) Following the procedures of Barry et al. [71], the data from the first 10 s of the EOPB were excluded, and consecutive 2-s epochs were extracted from the remaining resting state data for analysis. Epochs containing eye artifacts > ± 70 µV were excluded from analysis, and all data were manually inspected for additional EOG and EMG artifacts.

Correlation coefficient values were calculated for each epoch in the critical trials and EOPB by obtaining the Pearson correlation coefficient of the alpha waveforms of the pairs of electrode sites of interest (F3 and F4, F4 and P4, P3 and P4, and F3 and P3). This correlation coefficient function is a measure similar to coherence in that it determines the degree of similarity between two EEG signals.

The degree of similarity between two signals is assumed to reflect the similarity of the underlying neural processes and the functional connectivity of the brain areas involved [67,68]. While EEG coherence is a function of frequency and has a value between 0 and 1, the correlation function operates in the time domain and takes into consideration both the phase and polarity of the signal, and thus has a value between −1 and +1 [67, 68]. The resulting correlation coefficients were then standardized using the Fisher r-to-z transformation before performing parametric analyses (following procedures of Guevara and Corsi-Cabrera [67] and Guevara et al [68]).

5.3. Results

5.3.1. Self-Report Data

There was no significant difference between the number of internal thoughts (M = 12.86, SE = 0.63) and external thoughts (M = 11.03, SE = 0.62) reported during the study, $t(35) = 2.03$, $p = 0.15$. Due to excessive EOG artifacts, however, not all trials were included in the EEG analysis. All artifact-free trials were included in the analysis, and each subject whose data were included in the analysis contributed a minimum of three artifact-free trials per condition. These trials consisted of more internal thoughts (M = 9.25, SE = 0.55) than external thoughts (M = 7.25, SE = 0.53; Figure 1), $t(35) = 2.03$, $p = 0.02$. In addition, a minimum of 10 s of data (five 2-s epochs) for the resting state condition from each subject was included in the analysis.

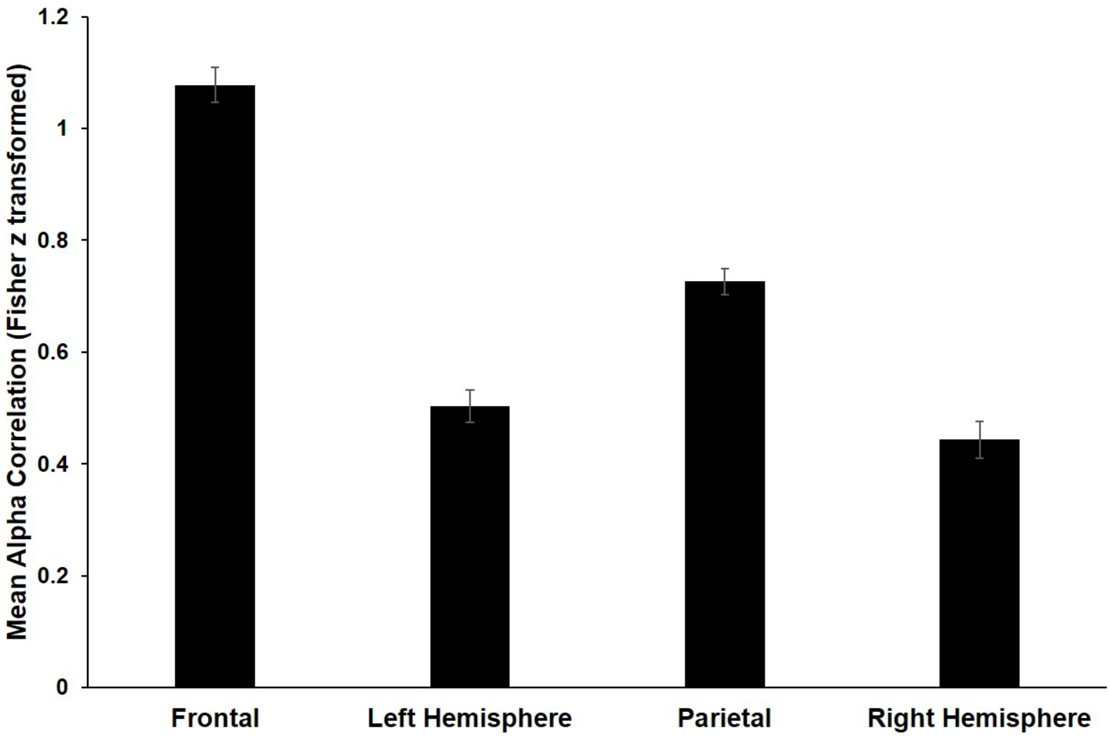

Figure 1. Mean alpha correlation for each region. All regions are significantly different from each other (ps < 0.001).

5.3.2. Electrophysiology Results

The inter-regional alpha correlation data were submitted to a repeated-measures ANOVA with conditions Region (frontal [F3–F4], parietal [P3–P4], right hemisphere [F4–P4] and left hemisphere [F3–P3]) and Thought Type (internal thoughts, external thoughts, and EOPB). Greenhouse-Geisser corrected *p*-values are reported. There was a main effect of Region, $F(3,105) = 187.84$, $p < 0.001$ (Figure 1), a main effect of Thought Type, $F(2,70) = 7.99$, $p = 0.001$ (Figure 2), and an interaction between the two factors, $F(6,210) = 2.57$, $p = 0.039$. Pairwise comparisons revealed significant differences in alpha correlation between all regions (*p*s < 0.001). In addition, pairwise comparisons revealed increased alpha correlation during internal thoughts compared to the eyes-opened resting baseline condition ($p < 0.01$), and no significant differences in alpha correlation between internal thoughts and external thoughts, or between external thoughts and the baseline condition (*p*s > 0.17). All comparisons were Bonferroni-corrected.

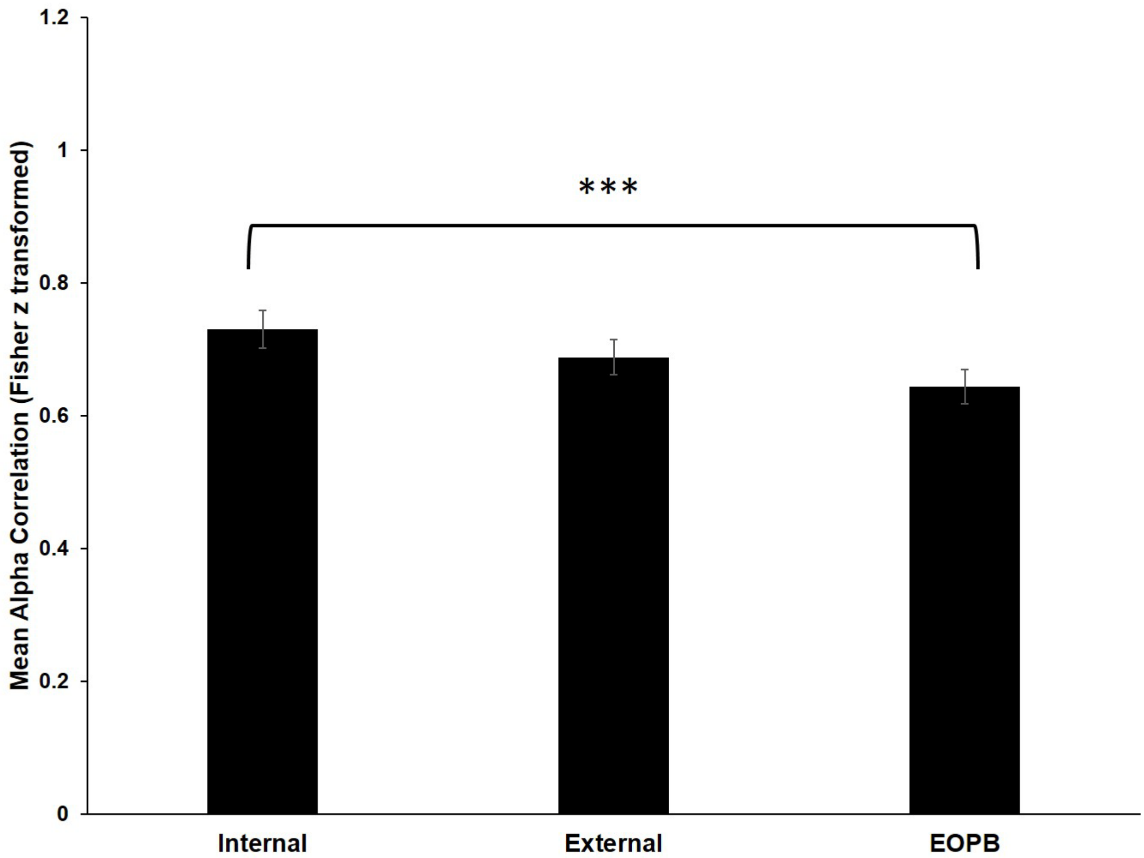

Figure 2. Mean alpha correlation of thought type. Mean alpha correlation of internal thoughts was significantly greater than mean alpha correlation of EOPB.

Planned contrasts were conducted to examine alpha correlation differences between each Thought Type within each Region. Results are displayed in Figure 3. Importantly, a significant difference was observed in alpha correlation between internal ($M = 0.78$, $SE = 0.03$) and external

(M = 0.70, SE = 0.03) thoughts within the parietal region, $t(35) = 2.49$, $p = 0.018$. Results also indicated a significant difference between internal thoughts and EOPB in the parietal region, $t(35) = -3.79$, $p = 0.001$, right hemisphere, $t(35) = -3.20$, $p = 0.003$, and left hemisphere, $t(35) = -3.68$, $p = 0.001$, and a significant difference between external thoughts and EOPB in the left hemisphere, $t(35) = 3.23$, $p = 0.003$.

Note that an initial analysis of 32 participants (16 female, M_{age} = 24.16, SD_{age} = 3.58) was conducted to examine the data for normal distribution. The Fisher r-to-z transformed correlation coefficients for each variable were tested for normality using the Kolmogorov-Smirnov test. Out of 12 variables (3 conditions × 4 regions), three did not show normal distribution. Upon further inspection of each variable, it was noted that one participant (female, age 22) was an outlier (defined by being between 1.5 and 3 interquartile ranges from the nearer edge of a boxplot) in all non-normally distributed variables.

Although the exact reason this participant was an outlier cannot be determined, the experimenter noted that the smallest electrode cap available was a size too large for the participant. Whether or not this skewed the data cannot be determined, but because of this factor and the observation that the participant was an outlier in each non-normally distributed variable, we decided to exclude the data from this participant from analysis and replace the data by running one additional gender- and age-matched participant. All variables in this dataset showed normal distribution. To contrast the two datasets and make sure that excluding one participant did not result in any extreme findings, a repeated-measures ANOVA was run for the initial dataset as well as for the new dataset with the outlier excluded and the new participant added.

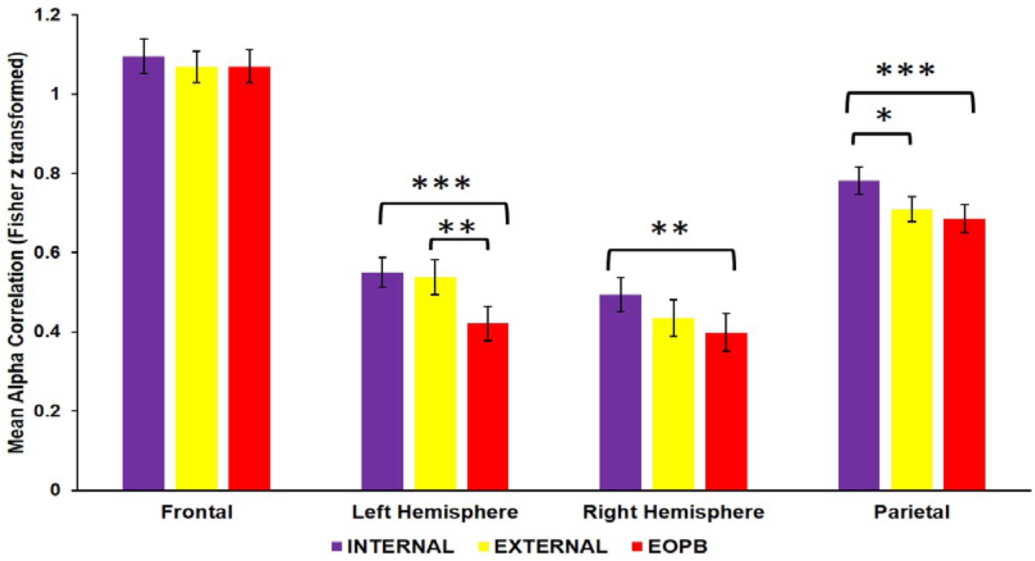

Figure 3. Mean alpha correlation for each thought type within each region. There was a significant difference between internal and external thoughts in the parietal lobe ($p = 0.018$), between internal thoughts and EOPB in the parietal region ($p = 0.001$), right hemisphere ($p = 0.003$), and left hemisphere ($p = 0.001$), and between external thoughts and EOPB in the left hemisphere ($p = 0.003$).

The brain electric microstates observed by Lehmann et al [59] were approximately 121 ms in duration and immediately preceded prompted recall reports of spontaneous, conscious experience (see Introduction). In addition, in a study on insight problem solving, Jung-Beeman et al [72] observed enhanced alpha activity for insight solutions during the −1.31 to −0.56 s interval preceding button-press responses. Although this latter example does not represent spontaneous thought per se, it does reflect a process in which a thought (in this case, a solution to a problem) suddenly enters awareness. The time courses of the processes observed in these two studies support our approach of examining 500-ms epochs that precede button-press responses by 400 ms to home in on the neural processes associated with the experience of a spontaneous thought.

6. General Discussion

Mind wandering and undirected thought processes are ubiquitous in human cognition, with reports indicating that individuals spend approximately 30% of the day in these mental states [73]. Although a large amount of research has typically examined these processes from the perspective that they are decoupled from the external environment, it is clear that spontaneous thoughts can arise from both stimulus-independent cognitions and stimuli in the environment [39,60] and likely involve dynamic interactions of memory and attention processes.

With our paradigm, in Studies 1–3, we found that, while performing a concentration task requiring one to focus on one's breathing, subjects reported on average less than two links per thought. Additionally, approximately half of subjects' thoughts were introspected to be unrelated to stimuli in the present environment. Because stimulus-independent thoughts can currently only be assessed through introspection, the latter datum is important in that it demonstrates the need to develop reliable introspective paradigms with which one can examine the precursors of spontaneous thought. It should be noted that at this point in our investigation, we are not able to determine the actual causes of one's spontaneous cognitions or if subjects are correct about their introspections. Nevertheless, with the findings presented here, we have taken an initial step in understanding the origins of one's spontaneous thoughts and in illuminating the understudied stream of consciousness. Whether correct or not, people believe that the genesis of their spontaneous thoughts tends to involve a short history, which is consistent with past theorizing and experimentation [16,34,74,75]. This short history of a thought suggests that spontaneous thoughts may not, on average, arise from truly spontaneous processes; instead, the short history may reflect that the extent to which subjects can remember the history of their thoughts is limited, for reasons worthy of further investigation. Consonant with our interpretations of our behavioral data, recent frameworks (e.g., [15]) propose that conscious thoughts usually stem from insuppressible, unconscious inferences and that these thoughts often stem from the immediate environment rather than from long, complicated chains of thought.

In order to study subjects' reported thought ancestries, we employed a new paradigm that allowed subjects to freely report the occurrence of their thoughts and to introspect the putative causes of their thoughts. While people may, on occasion, wonder what makes them think particular thoughts, in this study we requested that subjects report a specific number of links leading up to their thoughts. This is likely a task subjects had never encountered before. In order to clearly communicate the instructions of the task without increasing any experimental demand, we carefully worded the concept that thoughts “can be caused by other thoughts or things in the environment” and that there can be “one, none, or multiple links to a thought.” In this manner, subjects were not encouraged to report a certain number of thoughts or a certain number of links for each thought. Despite the novelty of the task, no subject in debriefing reported not understanding the link-counting task or the concept that thoughts can arise from previous thoughts or from things in the environment. To provide a standard environment during the procedure, subjects followed along to an audiotape recording that required one to concentrate on one’s breathing. This audiotape recording had been used successfully in a previous study in which subjects generated and reported spontaneous thoughts [5]. The concentration task was simple enough to allow subjects to freely experience spontaneous thoughts throughout the procedure.

To decrease demand characteristics, we intentionally did not describe to subjects what a thought is or what the field of psychology considers a thought to be (e.g., a conscious mental representation), nor did we explicitly instruct subjects to report only spontaneous thoughts (i.e., thoughts triggered automatically and without will). If subjects were truly following the audiotape at every moment, the only thoughts experienced would be thoughts triggered spontaneously. However, it is possible that subjects, at times, not only experienced spontaneous thoughts but also engaged in other thought processes such as directed mind wandering (cf., [19]). It is important to keep in mind that until these types of thoughts are explicitly distinguished, we cannot confirm that the data here reflect only spontaneous thought processes (or rather, that these data do not represent other thought processes). While we interpret the results presented here to reflect, on average, characteristics of spontaneous thought processes, additional studies utilizing this paradigm that provide explicit definitions of thoughts to subjects will have to address this issue further.

To our knowledge, Study 4 is the first investigation to use EEG functional connectivity analysis to examine, within a trial-by-trial millisecond timescale, the neural correlates of spontaneous thoughts reported by subjects to arise from either stimuli in the environment or stimulus-independent cognitions. The most compelling finding from this analysis is the contrast of alpha activity over the parietal cortex between internal and external thoughts. As predicted, alpha activity reflected internally-directed thought processes. Specifically, we observed increased functional connectivity over the parietal region within the alpha band for internal compared to external thoughts. These findings support previous research on attention and alpha band activity (e.g., [62,63]) that demonstrates the role of attention during internally-directed processes. It is possible that, as in Sauseng et al. [63], the results observed in this study reflect neural mechanisms that function to suppress attention to the external environment and enhance internally-directed processes. In this case, increased functional connectivity within alpha oscillations could serve to inhibit orienting to external stimuli [76] and provide a means by which thoughts unrelated to the external environment can arise. Interestingly, however, there were no differences between any of the thought conditions within the frontal region. This suggests that the mechanisms underlying spontaneous thought may rely on processes subserved by more posterior, parietal regions, at least across the time course in which we examined spontaneous thought.

We also observed increased connectivity during internal thoughts compared to the eyes-opened resting baseline condition, but no significant difference in alpha correlation between internal thoughts and external thoughts, or between external thoughts and baseline. From a certain standpoint, these results may seem surprising because resting conditions are typically assumed to elicit spontaneous thoughts and default mode network activation [19], leading one to expect that a resting baseline should most closely resemble the neural activity of internal thoughts. However, studies examining alpha activity and default mode network processes often employ eyes-closed resting conditions (e.g., [66]) as opposed to the eyes-opened condition utilized in the current study. It is possible that the robust suppression of alpha activity observed when eyes are open [71,77] could have diminished comparisons between the conditions in this study. Future directions can incorporate other baselines (e.g., an eyes-closed resting baseline and an internally-focused baseline) in order to draw further conclusions.

6.1. Limitations of the Initial Studies

Our new paradigm for studying the introspected sources of a thought is not without some limitations. Although care was taken to ensure that each subject understood the instructions of the task, the number of thoughts and the minimal average number of links reported by subjects may have been consequences of the measurement itself—that is, the activity of reporting thoughts and links. The process of reporting spontaneous thoughts and introspecting the number of links could have triggered other, related thoughts. Because the studies presented here did not ask subjects to report the content of their thoughts, we cannot directly determine the extent to which the activity influenced subsequent thoughts and links. However, we believe it is unlikely that the current data reflect this measurement effect: the thought content reported incidentally by a subset of the subjects was unrelated to the act of introspecting and of reporting thoughts and links, suggesting that the activity itself did not strongly influence subsequent spontaneous thoughts and the numbers of links reported. In addition, if the activity itself strongly influenced the nature and experience of additional thoughts and links, subjects would likely experience a large number of thoughts during the study. However, the average number of thoughts reported across Studies 1-3 was fewer than 12. Nevertheless, the influence of our current measurement on the number of thoughts and links remains open for investigation, and future studies that incorporate reports of thought content could investigate this issue.

Other shortcomings of this paradigm include working memory limitations in which subjects were only able to keep track of a limited range of their mental processes [e.g., 33,78]. This shortcoming has been treated at length (see [28]), and could be more informative than appears to be the case at first glance. For example, it is possible that the link-counting task was too cognitively demanding and that, with a different introspection method, subjects would have reported a greater number of links leading up to their spontaneous thoughts. Yet, no subject reported difficulty performing the task, and it is most likely that any working memory limitations regarding introspection present in this study are also inherent to introspection in general and constrain one's interpretation and understanding of spontaneous thoughts outside the laboratory as well.

It is important to point out that the task instructions in Studies 1–3 read "When you have a thought, write an 'X.' Think about what caused your thought, and next to the 'X' write the number of links that led from the initial thought or thing in the environment to your thought." If subjects took these instructions seriously, they would immediately mark an 'X' not when the spontaneous thought occurs, but when the introspected precursors, that is, the preceding thoughts, occur. In this situation, subjects would never be able to report more than zero links per thought. We do not think that is the case here, however. In both studies there was a range in the number of links reported. This suggests that the spontaneous thoughts subjects reported may be the result of rapid successive cognitive processes (constituting the 'building blocks' of a spontaneous thought; see Lehmann et al. [59]) which led up to thoughts that subjects reflected upon afterwards: one could speculate that perhaps subjects are conscious of these precursors of spontaneous thought (i.e., links) but that these cognitive processes transpire so rapidly that they terminate before subjects can report the preceding links as individual thoughts. An intriguing question that proceeds from this is whether subjects are aware of these preceding cognitive processes (i.e., the thought precursors) all along or only after realizing that they experienced a spontaneous thought and then trying to 'pull' the precursors into awareness to report the number of links. Future research could examine these questions in detail.

We acknowledge that some necessary parts of the instructions, such as the mention that thoughts can be influenced by external stimuli, may introduce some biases in subjects. However, the task instructions explain that thoughts can be caused by other thoughts as well, and that sometimes thoughts may not appear to arise from any link. We aim with this wording to minimize potential bias by introducing subjects to all possible options equally. An additional limitation is the various cultural beliefs that may exist among subjects as to what constitutes a thought and what factors influence the perceived causality of experienced thoughts, as well as how concepts and ideas may be related to one another (e.g., [79]). It is worth noting that our findings from Study 1 were replicated in Studies 2 and 3, suggesting that there are consistent patterns in the manner in which people understand and introspect the causes of their thoughts.

The studies presented here provide a quantitative measure of individuals' introspections of the determinants of thoughts comprising the stream of consciousness. Again, we do not claim that these introspective reports reflect in any way what may be the actual causes of subjects' thoughts or the underlying, neuronal processes that result in spontaneous thoughts. With implications for the understanding of the potential neural signatures of thought ancestry, recent research has shown that memories formed in a given context become neurally linked with each other [80].

Additionally, although we replicated our results from the first study in the second and third studies, despite the studies occurring on different days and times and in different classrooms, it is possible that these findings would differ if this study were run in a very different environment (e.g., outdoors), in a novel environment, or while performing a different task. This may be the case particularly for the number of thoughts attributed to environmental stimuli (which was about half of all thoughts in Studies 2 and 3). In the next section, we address the implications of this type of paradigm and how it can be modified to examine sequences of thought in various environments and internal states.

With any procedure that employs self-report as a dependent variable, there is the risk that subjects were not able to accurately introspect and report their experiences. All of the future variants rely on introspection as a means to understand cognitive processes. This dependent measure has been criticized throughout the history of psychology [28,81]. (William James [30] can be credited with stating that using introspection as a technique to understand the stream of consciousness is "like seizing a spinning top to catch its motion, or trying to turn up the gas quickly enough to see how the darkness looks" [p. 244].) In addition, there are many cases in which it has been documented that people cannot accurately introspect the cognitive processes underlying their behaviors, choices, and judgments (e.g., [82]). Regarding thought sequences, it seems that people have an intuitive idea regarding what they are, as in the quotidian expression, 'string of thoughts' or 'line of reasoning.' However, such evidence is anecdotal and does not shed light on the actual difference between, say, a single thought with many links and a sequence of many thoughts. Variants of the present paradigm could be used to illuminate this issue. For example, in a variant of the paradigm, subjects could be asked to report about, not just the number of links leading to a spontaneous thought, but the number of topics covered in the sequence of links leading to the given thought. It is worth pointing out that the use of EEG measures to study consciousness is also surrounded by some controversy. For example, based on substantial data and compelling theorizing, Merker [83] proposes that cortical EEG does not reflect conscious processing. In addition, research involving the technique of meditation is not without controversy (see discussion in [84–86].

Despite these limitations, across all studies, subjects reported on average the same number of internal and external thoughts, suggesting that there are consistent patterns in the manner in which people understand the task and introspect the causes of their thoughts. (In Study 4, the number of internal and external thought trials used for the analysis did significantly differ, however, as more external thought trials were omitted from analysis due to EOG artifacts. This may have been the result of more eye blinks induced during external thoughts, when subjects may have been attending to visual stimuli in the environment.) In all the studies, we took care to present all instructions both visually and verbally, and subjects were permitted to ask for clarification on any aspect of the study.

In Study 4, we instructed subjects to clear their thoughts at the start of each trial so that each subject could begin each trial in a similar mental state. However, trying to keep one's mind clear, especially for ten seconds as was instructed in this study, can be challenging. Many subjects reported in the funneled debriefing that this was the most difficult aspect of the study. Although, in regard to spontaneous thought, we were not interested in this portion of each trial, the difficulty of clearing one's mind may have affected subjects' behavioral performance and neural activity throughout the entire study. Future investigations could reduce the amount of time for which subjects are instructed to clear their thoughts. In our study, the instructions remained constant across all trials, ensuring that all comparisons between internal and external thoughts arose from trials in which subjects performed similar tasks.

It should be emphasized that the results from Study 4 need to be interpreted conservatively and as an important but incremental step in understanding the neural correlates, and cognitive dynamics, associated with spontaneous thought. Considering that there is no agreed upon scientific definition of a thought (cf., [87]), we are dependent upon subjects to understand what a thought is and to report their thoughts in an accurate and consistent manner. However, although there is no agreed-upon definition of a thought itself, we did provide to subjects clear explanations based on previous research [49] of how internally- and externally-directed thoughts are differentiated, and no subject reported confusion about the two terms. In addition, we can only estimate the average length of time that a thought may occupy. In Study 4, we chose 500-ms epochs for our analysis based on findings in the literature. Additional analyses that include longer epochs or epochs that extend up until button-press responses may provide further information on the dynamics of spontaneous thought and neural differences between internally- and externally-triggered thoughts. Future steps in this line of investigation may compare spontaneous thoughts to different resting state baselines. In the current analysis, we compared spontaneous thoughts to an eyes-opened post-task resting state. As addressed above, alpha correlation was lower for this resting state compared to internal thoughts, an unexpected finding. Analyses with an eyes-closed resting state baseline condition or internally-focused baseline condition could provide further information.

6.2. Implications and Future Directions

The primary aim of our research project was to provide a new, quantitative paradigm with which to begin to illuminate how people apprehend the Jamesian stream of consciousness leading up to a spontaneous thought. Because many factors may influence the types of thoughts and the numbers of links per thoughts that subjects experience, the conclusions obtained from the current studies should be taken, not as absolute claims regarding the nature of spontaneous thought, but as context-dependent observations that have the potential to vary based on a subject's environment, task instructions, and other factors. Our paradigm could be used to test a wide range of predictions concerning the nature of these internal events. For example, current research focusing on how cognitive control shields internal thinking from external distractions (e.g., the presence of noise or of incentive stimuli) reveals that individuals who experience the most task-unrelated cognitions show decreased tendencies to respond to distractors in a cognitive task, as if their internal thoughts were protected from external influence [88]. Complementary evidence stems from research on the relationship between working memory capacity (a phenomenon associated with cognitive control) and the occurrence of task-unrelated thought. In this research, it was found that individuals with higher working memory capacity experience more task-unrelated thoughts during an undemanding task, as if working memory capacity supports the capacity to sustain task-unrelated thoughts [89,90].

In light of these developments, one could make several predictions involving our new paradigm. For example, it could be proposed that, during an undemanding cognitive task, subjects with high working memory capacity would have the most links per spontaneous thought, because the high working memory capacity would shield their internal thoughts from external distraction. In addition, one could propose that, with the current method, the mean number of links per thought would be inversely related to the level of noise or distraction in the external environment, because such external stimulation would challenge the shielding of internal processes. In addition, providing subjects with longer periods of introspection could provide a more accurate assessment of links leading up to a spontaneous thought, which could potentially yield an increased number of links reported. Last, future variants of the paradigm could have subjects input their thoughts via computer, which would eliminate the problems associated with handwritten responses (which can be illegible).

Our new paradigm provides an additional, quantitative tool with which to begin to illuminate the streams of consciousness leading to spontaneous thoughts. In addition, our paradigm can be combined with thought-sampling methods that periodically cue subjects to report their thought content in a real-time manner (e.g., [53]). For example, the experimental technique of experience sampling could provide a fruitful addition to this line of research on spontaneous thought. Experience sampling involves probing subjects with a cue to report what they were thinking immediately before presentation of the cue (e.g., [51,53]). This method has been employed in several studies examining spontaneous thought and mind wandering (e.g., [59]; see review in [51]). The technique is beneficial in that it does not require that subjects emit a physical response, and it does not interrupt the natural flow of thought or require meta-awareness of thought [51]. The current paradigm allows for a representation of subjects' thoughts when these thoughts are naturally noticed and "caught" by subjects. It allowed us to examine the neural correlates of spontaneous thoughts based on the exact time at which subjects reported experiencing them, an advantage that experience sampling does not have. This is a particularly beneficial characteristic of the current paradigm because it is similar to experiences in real life when one spontaneously thinks about something and wonders 'what made me think that?' However, the thought-sampling methods described by Christoff et al. [53] are beneficial in other contexts as they allow for a natural flow of the stream of consciousness and do not require subjects to actively monitor their internal environment for thoughts. It is possible that, when subjects are not required to constantly monitor their thoughts, they may experience different types of thoughts, different numbers of links per thoughts, or both. Our paradigm could be modified to incorporate this type of thought-sampling method to investigate this idea.

In conclusion, by combining introspective reports with neural measures on sub-second timescales, we have taken a novel step in examining the mechanisms of spontaneous thought. We hope that our project builds on the growing cognitive and neuroscientific literatures that examine processes which, for a long time in intellectual history, one (including Freud) could only speculate about.

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