Self-Reflection and the Inner Voice: Activation of the Left Inferior Frontal Gyrus During Perceptual and Conceptual Self-Referential Thinking

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Abstract: Inner speech involvement in self-reflection was examined by reviewing 130 studies assessing brain activation during self-referential processing in key self-domains: agency, self-recognition, emotions, personality traits, autobiographical memory, and miscellaneous (e.g., prospection, judgments). The left inferior frontal gyrus (LIFG) has been shown to be reliably recruited during inner speech production. The percentage of studies reporting LIFG activity for each self-dimension was calculated. Fifty five percent of all studies reviewed indicated LIFG (and presumably inner speech) activity during self-reflection tasks; on average LIFG activation is observed 16% of the time during completion of non-self tasks (e.g., attention, perception). The highest LIFG activation rate was observed during retrieval of autobiographical information. The LIFG was significantly more recruited during conceptual tasks (e.g., prospection, traits) than during perceptual tasks (agency and self-recognition). This constitutes additional evidence supporting the idea of a participation of inner speech in self-related thinking.

Keywords: Self-awareness, self-reflection, self-referential activity, inner speech, self-talk, verbal labeling, left inferior frontal gyrus, language, conceptual self-domains, perceptual self-domains, brain-imaging.

1. INTRODUCTION

Self-referential activity is currently the target of numerous brain-imaging studies aimed at determining what brain areas get reliably activated during self-reflection tasks. The consensus is that the following regions underlie self-related processing: cortical medial structures, which include ventromedial and dorsomedial prefrontal cortex, lateral prefrontal cortex, precuneus, insula, temporoparietal junction, and anterior/posterior cingulate cortex [for reviews see 1-6].

Ruby and Legrand [7] recently proposed that memory recall and inferential reasoning constitute particular computational ingredients recruited when one is engaged in self-referential processing. That is, most self-reflection tasks employed in brain-imaging studies require one form or another of memory and evaluation involving a certain degree of uncertainty (e.g., does this personality trait apply to me?). Consistent with this hypothesis, most aforementioned brain areas recruited during self-reflection are also activated during memory recall and inferential reasoning.

Another elementary process potentially recruited during self-reflection is the inner voice [8-12]. Verbalizing one’s characteristics to oneself or engaging in a complex silent verbal self-analysis is postulated to facilitate the identification, storage, and retrieval of self-information [for details see 13]. Inner speech is known to serve various important cognitive functions [for reviews see 14-16], among which are planning [17], self-regulation [18], self-control [19], and memory [20], including working memory [21]. The idea that one often “thinks” (including about oneself) in words is certainly not new (Plato, cited in [22]); what is novel is empirical evidence establishing connections between self-reflection and the inner voice. To illustrate, people report talking to themselves mostly about themselves [23]. Various validated frequency measures of self-focus and self-talk significantly correlate [e.g., 24, 25]. Deterioration of inner speech following a left lateralized stroke is associated with self-awareness deficits [10].

Morin and Michaud [26] noted that inner speech production consistently recruits the left inferior frontal gyrus (LIFG) and reported a relatively high incidence of LIFG activation during self-reflection tasks, suggesting inner speech activity during at least some self-information processing. More specifically, this team reviewed 59 brain-imaging studies of self-awareness in the following self-domains: agency, self-recognition, emotions, personality traits, autobiographical memory, and preference judgments. Resting state (REST) studies were also included because of the introspective quality of that state [20]. Fifty-six percent of all studies reviewed identified LIFG and presumably inner speech activity during self-reflection tasks. In addition, the LIFG was more frequently recruited during conceptual self-tasks (e.g., emotions, traits) than during perceptual self-tasks (agency and self-recognition). This possibly suggests that more abstract self-aspects need to be verbalized in order to be fully brought to consciousness.

The main goal of the present meta-analysis was to expand Morin and Michaud’s original results [26] by combining them with a new set of brain-imaging studies of self-reflection published since 2006. The overall principle here [reverse inference; see 27] is that researchers can infer what particular thought processes are solicited during a given social cognitive task by concentrating on peripheral structures instead of on a core network. For example, retrieval of autobiographical information often activates...
observation of an activation of the LIFG during verbal working memory tasks [45, 46]. Hence the negatively affects performance on cognitive control and articulatory suppression (i.e., blocking inner speech) actually require subvocal articulation. For instance, conceivable that most, if not all, listed functions above [40], selection among competing alternatives [41, 42], control [38], working memory [39], language unification involves covert repetition of verbal material [e.g., 31-33]. Moreover, accidental destruction or temporary disruption (using repetitive transcranial magnetic stimulation) of the LIFG interferes with inner speech [34-36]. Note that other brain areas are associated with inner voice use, among which Wernicke’s area, the supplementary motor area, insula, and superior parietal lobe on the left side, as well as right posterior cerebellar cortex [for a review see 37].

It has been proposed that the LIFG serves additional functions besides covert speech per se, including cognitive control [38], working memory [39], language unification [40], selection among competing alternatives [41, 42], response inhibition [43], and action understanding [44]. It is conceivable that most, if not all, listed functions above actually require subvocal articulation. For instance, articulatory suppression (i.e., blocking inner speech) negatively affects performance on cognitive control and verbal working memory tasks [45, 46]. Hence the observation of an activation of the LIFG during both inner speech production and tasks designed to test the aforementioned functions. In other words, one could argue that LIFG activation most often signifies inner speech use, be it for cognitive control or working memory purposes, or for any other possible reasons, including self-reflection. Given this, and considering the fact that self-tasks presented in the next section most unlikely involve cognitive control, working memory, language unification, selection among competing alternatives, response inhibition, and action understanding, LIFG activity in this review was interpreted as indirect evidence of inner speech use by participants.

The first objective of the present meta-analysis was to determine if LIFG activation is observed in a significant number of brain-imaging studies of self-reflection. Different ways of classifying self-dimensions exist [see 2, 3]. In this paper self-tasks were put into the following self-domains: agency, self-recognition, emotions, personality traits, autobiographical memory, and miscellaneous. This latter category included experiments imaging participants thinking about their intentions, hopes, aspirations, mental states, preferences, as well as self-evaluation and prospect tasks (i.e., thoughts about one’s future).

A second aim was to compare LIFG activation in perceptual (agency and self-recognition) and conceptual (e.g., autobiography, traits) self-domains, where inner speech use is hypothesized to be more important in the latter. Perceptual (sensory) self-information refers to products of one’s direct experience with oneself (e.g., the body) or environmental stimuli (e.g., other persons, mirrors) that identify the self. Conceptual self-information constitutes data about the self that is not available to immediate perceptual experience and that presumably requires mental representation to be accessible to consciousness. This division between perceptual and conceptual self-domains echoes the distinction between physical and psychological selves proposed by Gillihan and Farah [2, 47]. Perceptual self-information such as one’s face during self-recognition, because of its visual and concrete nature, most probably does not need to be verbally labeled (e.g., “this is my face”) to successfully complete the task. Agency tasks typically involve evaluating the degree of one’s participation in a given action and thus mostly rely on kinesthetic information. Reflection on more abstract self-dimensions such as past memories and intentions however, possibly entail subvocal speech (e.g., “I spent last summer at my brother’s place”; “I want to go swimming”) to be fully brought to one’s attention.

2. METHOD

English-language papers published between September 2006 and August 2010 were identified from searches using Medline, Psycarticle, and Psycinfo, as well as the Psychology and Behavioral Sciences Collection. The reference section of each article was scrutinized for additional studies. Review articles were also carefully examined. Inclusion criteria for selection of articles were all studies measuring brain activity using hemodynamic methods (Positron Emission Tomography [PET] and functional magnetic resonance imaging [fMRI]) during self-related tasks pertaining to the aforementioned self-domains. Exclusion criteria were: (a) articles using Theory-of-Mind (ToM) tasks, as opposed to purely self-referential tasks [e.g., 48]; (b) electrophysiological studies using event-related potentials, as well as those employing EEG and Transcranial Magnetic Stimulation [e.g., 49]; (c) studies imaging clinical populations exclusively [e.g. 50]; and (d) studies not reporting all areas of activation and uniquely focusing on regions of interest [e.g., 51]. ToM and self-reflection abilities are linked in complex ways [see 52] and common brain areas are recruited when one both introspects and thinks about others’ mental states [53]. Nonetheless, ToM abilities fundamentally differ from self-reflection abilities in that the former focuses on other social agents whereas the latter exclusively pertains to the self [54]. This is why we excluded ToM studies from the present meta-analysis.

The application of this selection process led to the identification of 68 articles; we added to these articles 59 previously identified by Morin and Michaud [26] in the same self-domains. These authors used the same search and selection processes described above for articles published.

1 Keywords were searched in the title of articles. Keywords used were: agency, autobiographical, autobiography, automatic, brain, cortical, emotion awareness, emotion recognition, fMRI, future thoughts, intentions, introspection, judgments, mental time travel, neural correlates, neural substrates, neuroanatomy, personality traits, PET, preferences, self, self-awareness, self-face, self-processing, self-projection, self-recognition, self-referential, and self-reflection.
prior to September 2006. In all, we thus examined 127 articles containing 130 individual studies (some papers contained more than one study). Frequency of LIFG activation reported in these articles is presented in the Results section. Note that we uniquely concentrated on LIFG recruitment during self-conditions and deliberately ignored control conditions because inner speech participation during these control conditions is likely. To illustrate, inner speech use most likely will be recruited during a control task consisting in judging how socially desirable personality traits are, as in Craig et al. [55]. As mentioned earlier, inner speech serves various purposes in addition to the processing of self-information; control tasks such as encoding semantic information or making decisions about statements of factual knowledge often recruit subvocal speech. Thus we are not making the claim that inner speech use is special to the self; indeed, recent reviews rather suggest that there is actually little special about or unique to the self [2, 7]. However, we hypothesize that the inner voice represents a privileged cognitive tool the self uses when assessing itself.

3. RESULTS AND DISCUSSION

3.1. Overview

Fig. (1) depicts the percentage of studies in which LIFG activity was observed in all selected self-domains. Seventy two of all 130 studies (55.3%) indicated activation of the LIFG during self-awareness tasks. Percentages for each self-domain were: 76.9 for autobiography, 56.7 for traits, 53.3 for emotions, 27.3 for agency, and 23.5 for self-recognition. The “miscellaneous” self-domain (66.7%) included studies using evaluative judgment tasks involving the assessment of one’s own preferences in order to produce a judgment, REST studies, as well as future-oriented thinking studies.

We submit that 55% represents a significant percentage, especially when compared to LIFG activation percentages that have been observed during various non-self tasks. Cabeza and Nyberg [29] reviewed studies of brain activations in various non-self cognitive domains such as attention and procedural memory. We excluded language

| Domain                        | N of Studies Reviewed | N of Studies Reporting LIFG Activation (BA 44/45/47) | Percentage of LIFG Activation |
|-------------------------------|-----------------------|------------------------------------------------------|-------------------------------|
| Attention                     | 39                    | 3                                                    | 7.7                           |
| Perception                    | 42                    | 8                                                    | 19                            |
| Imagery                       | 18                    | 3                                                    | 16.7                          |
| Non-verbal episodic memory encoding | 17                  | 5                                                    | 29.4                          |
| Non-verbal episodic memory retrieval | 70                | 10                                                   | 14.3                          |
| Priming                       | 16                    | 6                                                    | 37.5                          |
| Procedural memory             | 27                    | 1                                                    | 3.7                           |
| ALL                           | 229                   | 36                                                   | 15.7                          |

Table 1. LIFG Activation Observed in Various Non-Self Domains (Based on 26). Language and Working Memory Domains are not Reported
Table 2. Agency studies. (P) = Employed PET

| Paper | Self-task | LIFG Activation |
|-------|-----------|-----------------|
| Farrer & Frith [58] (P) | Driving circle along T-shaped path either by oneself or experimenter | NO |
| Farrer et al. [59] (P) | Providing accurate/inaccurate visual feedback while performing hand movements | NO |
| Knoblich et al. [60] | Deciding temporal delay between hand movements & visual feedback | NO |
| Leube et al. [61] | See [59] | NO |
| McGuire et al. [62] (P) | Providing accurate/inaccurate auditory feedback while reading aloud | NO |
| Powell et al. [63] | Choosing one of 4 deck cards presented on a screen | NO |
| Ruby & Decety [64] (P) | Imagining self vs other movements | NO |
| Salomon et al. [56] | Deciding if hand movements are self- or other-generated | NO |
| Vinogradov et al. [65] | Judging if words were preselected by self or experimenter | YES |
| Waga et al. [66] | Imagining rotating one’s body | YES |
| Yomogida et al. [67] | Controlling character’s movements/actions with joystick | YES |

and working memory studies, and observed that only 16% of 213 studies report LIFG activity (see Table 1). Again, in this perspective an activation of the LIFG in 55% of all self-referential thinking studies reviewed appears significant.

Given the nature of self-tasks reviewed here (see below for descriptions), this LIFG activity most probably reflects inner speech use instead of other possible LIFG functions such as response inhibition or action understanding. These results thus tentatively support the view that the inner voice substantially participates in at least some forms of self-referential processing.

Consistent with the idea of a greater inner speech involvement in conceptual self-domains, we found that 63.7% of all conceptual studies (n = 102; autobiography, miscellaneous, emotions, and traits) reported activation of the LIFG, as opposed to 25% of all perceptual studies (n = 28) of agency and face/voice self-recognition. This difference is statistically significant, $\chi^2(1) = -3.770, p =.005$. This supports the view of a differential involvement of inner speech across self-domains, where perceptual self-dimensions (e.g., one’s face) can be consciously perceived without words, whereas conceptual self-aspects (e.g., autobiography; prospection) most probably demand verbalization.

3.2. Agency and Self-Recognition

All Tables included below detail (1) the authors of individual articles, (2) self-tasks used, and (3) the presence or absence of LIFG activation. Note that unless otherwise indicated all studies used fMRI imaging technology. Table 2 presents 11 reviewed articles in the agency self-domain. A typical agency study [e.g., 56] invites participants to decide if they are responsible for the movement of their hand [for a review see 57]. Three of the agency studies out of 11 (27.3%) reported LIFG activation.

Table 3 shows 17 reviewed articles in the self-recognition domain. Most self-face recognition studies [e.g., 68] involve participants judging if a face seen on a screen is their own or that of another person [for reviews see 69, 70]. Four self-recognition studies out of 17 (23.5%) reported LIFG activation. Sugiuira et al.’s observation [71] that “(…) covert naming often accompanies recognition of a familiar face, but rarely occurs during visual self-recognition” (p. 147) is consistent with the notion that self-face recognition unlikely necessitates verbal labeling. Indeed, multiple brain networks for visual self-recognition have been identified [see 72], none of which include the LIFG).

3.3. Personality Traits

Most early self-reflection studies consisted in asking participants to determine if adjective traits were self-descriptive [e.g., 55, 88]. This represents a simple, straightforward, and yet effective way of inducing self-focus, as one’s personality certainly constitutes a central aspect of the self. Twenty one out of 37 personality trait studies (56.7%) reported LIFG activation (see Table 4). Current neuropsychological and brain-imaging evidence suggests that once personality traits have been inferred by reflecting on specific and repeated behavioral instances, their retrieval becomes rather automatic and does not require autobiographical recollection [89]. This could explain why 16 of the reviewed studies did not find brain activity suggestive of verbal processing. It remains unclear why some studies did report the target activation while others did not despite using identical experimental tasks.

3.4. Autobiographical Memory

Remembering past personal events represents a fundamental human mental activity connected in complex ways to autonoetic consciousness and the self [123-125]. Thinking about one’s past and imagining one’s future (prospection; see next section) seem to depend on common underlying regions, notably the medial prefrontal cortex and lateral temporal cortices [126]. In a representative study of autobiographical memory [e.g., 127], some of the participants’ past personal events are collected prior to scanning and each event gets associated with a verbal or visual cue; cues are then presented during scanning and volunteers are asked to recall the associated events in details. Table 5 shows that 20 of the 26 studies analyzed (76.9%) reported LIFG activation. This constitutes the highest activation rate of all self-domains. Although introspection suggests that we often replay past personal episodes in “pictures”, some studies indicate that we also use inner speech when developing self-narratives [128-130]. Indeed, a left ventrolateral activation which includes the LIFG is often observed in autobiographical remembering [28, 131].
### Table 3. Self-recognition Studies. (P) = Employed PET

| Paper                      | Self-task                                      | LIFG Activation |
|----------------------------|------------------------------------------------|-----------------|
| Devue et al. [73]          | Judging if face is self or other               | YES             |
| Kaplan et al. [74]         | See [73]                                       | NO              |
| Kircher et al. [75]        | See [75]                                       | YES             |
| Kircher et al. [76]        | See [73]                                       | YES             |
| Morita et al. [77]         | See [73]                                       | NO              |
| Perrin et al. [78] (P)     | Listening to one’s, unfamiliar, & common names | NO              |
| Platek et al. [79]         | See [73]                                       | NO              |
| Platek et al. [80]         | See [73]                                       | NO              |
| Platek & Kemp [81]         | See [73]                                       | NO              |
| Sachdev et al. [82]        | Judging if face & body shape are self or other | NO              |
| Sugiura et al. [83] (P)    | See [73]                                       | NO              |
| Sugiura et al. [71]        | See [73]                                       | NO              |
| Sugiura et al. [84]        | Judging if face & voice are self or other      | YES             |
| Sugiura et al. [68]        | See [73]                                       | NO              |
| Sui & Han [85]             | See [73]                                       | NO              |
| Uddin et al. [86]          | Deciding if faces are composites of oneself or other | NO           |
| Uddin et al. [87]          | Viewing full body images of self               | NO              |

### Table 4. Personality Trait Studies. (P) = Employed PET

| Paper            | Self-task                                                      | LIFG Activation |
|------------------|---------------------------------------------------------------|-----------------|
| Blackwood et al. [90] | Judging if various traits, activities & emotions are self-descriptive | NO              |
| Chiao et al. [91]  | Judging self-descriptiveness of sentences                      | NO              |
| Craik et al. [55] (P) | Judging if adjective traits are self-descriptive               | YES             |
| D’Argembeau et al. [92] | See [55]                                               | YES             |
| D’Argembeau et al. [93] | See [55]                                               | NO              |
| Farb et al. [94]   | See [55]                                                      | YES             |
| Fossati et al. [95] | See [55]                                                      | NO              |
| Gutchess et al. [96] | See [55]                                                      | YES             |
| Han et al. [97]    | See [55]                                                      | YES             |
| Heatherton et al. [98] | See [55]                                                  | YES             |
| Jenkins & Mitchell [99] | See [55]                                                | NO              |
| Kelley et al. [100] | See [55]                                                      | YES             |
| Kircher et al. [75] | Judging if adjective traits & physical characteristics are self-descriptive | YES             |
| Kjaer et al. [101] (P) | Silently thinking about one’s traits & physical appearance    | YES (physical appearance only) |
| Lemogne, le Bastard, Mayberg, et al. [102] | See [55]                                               | NO              |
| Lemogne, Mayberg, Bergouignan, et al. [103] | See [55]                                               | YES             |
| Lieberman et al. [104] | See [55]                                               | YES             |
| Lou et al. [105] (P)    | See [55]                                                      | YES             |
| Macrae et al. [106]  | See [55]                                                      | YES             |
| Modinos et al. [107] | Judging self-descriptiveness of sentences about personal qualities | NO              |
| Moran et al. [108]    | See [55]                                                      | NO              |
| Moran et al. [109]    | See [55]                                                      | YES             |
| Ng et al. [110]       | See [55]                                                      | YES             |
| Ochsner et al. [111]  | See [55]                                                      | YES             |
Table 4. contd….

| Paper                        | Self-task                                                                 | LIFG Activation |
|------------------------------|---------------------------------------------------------------------------|-----------------|
| Pfeifer et al. [112]         | See [91]                                                                   | YES             |
| Powell et al. [63]           | See [55]                                                                   | YES             |
| Rameson et al. [113]         | See [55]                                                                   | NO              |
| Ries et al. [114] (P)        | See [55]                                                                   | NO              |
| Schmitz et al. [115]         | See [55]                                                                   | NO              |
| Schmitz et al. [116]         | See [55]                                                                   | NO              |
| Vanderwal et al. [117]       | See [55]                                                                   | YES             |
| Wu et al. [118]              | See [55]                                                                   | NO              |
| Yao et al. [119]             | See [55]                                                                   | YES             |
| Yoshimura et al. [120]       | See [55]                                                                   | NO              |
| Zhang et al. [121]           | See [55]                                                                   | NO              |
| Zhu et al. [122]             | See [55]                                                                   | YES             |

Table 5. Autobiographical Memory Studies. (P) = Employed PET

| Paper                                    | Self-task                                                                 | LIFG Activation |
|------------------------------------------|---------------------------------------------------------------------------|-----------------|
| Botzung, Denkova, Ciuciu, et al. [132]   | Recalling autobiographical memories (AM) in response to visual cues        | YES             |
| Botzung, Denkova & Manning [133]         | Assessing self-descriptiveness of past personality traits                 | NO              |
| Burianova et al. [134]                   | Recalling last time one experienced event depicted on photograph          | YES             |
| Cabeza et al. [135]                      | Remembering if pictures where taken by self or others                     | YES             |
| Campitelli et al. [136]                  | Recalling if chess moves were made by self or other                       | YES             |
| Conway et al. [137] (P)                  | Generating AM following presentation of cue words                         | YES             |
| Dasehaar et al. [127]                    | Recalling AM in response to visual cues                                   | YES             |
| Fink et al. [138] (P)                    | Listening to & visualizing personal & non-personal AM                     | NO              |
| Gilboa et al. [28]                      | Remembering context of recent/remote episodes shown on photographs        | YES             |
| Harrison et al. [139]                    | Recalling sad past personal events                                       | YES             |
| Kelly et al. [140]                       | Recalling AM of painful & non-painful episodes in response to visual cues  | YES             |
| Kross et al. [141]                       | Recalling AM of negative episodes in response to visual cues              | YES             |
| Levine et al. [142]                      | Listening to verbal descriptions of AM                                    | YES             |
| Loughead et al. [143]                    | Recalling interpersonal life events                                      | YES             |
| Maguire & Mummery [144] (P)              | Indicating if read statements of past personal episodes were participants' | NO              |
| Maguire et al. [50]                     | See [144]                                                                  | NO              |
| Maguire & Frith [145]                    | See [144]                                                                  | YES             |
| Moran et al. [108]                      | Viewing words depicting personal semantic information                     | YES             |
| Oddo et al. [146]                       | Recalling AM in response to visual cues                                   | NO              |
| Piefke et al. [147]                     | Remembering positive / negative & old / recent past personal events       | YES             |
| Piolino et al. [148] (P)                 | Recalling unique personal events                                         | YES             |
| Rabin et al. [149]                      | Recalling personal events in response to visual cues                      | NO              |
| St-Jacques et al. [150]                  | Recalling which picture was taken first after picture taking sessions     | YES             |
| Spreng & Grady [151]                    | Recalling personal events in response to visual cues                      | YES             |
| Summerfield et al. [152]                | See [127]                                                                  | YES             |
| Svoboda & Levine [153]                  | Recalling personal events in response to auditory cues                    | YES             |

3.5. Emotions

The notion that verbal labeling of emotions enhances emotion awareness is not new [see 154]. It seems plausible to suggest that verbally identifying one’s feelings through inner speech (e.g., “I feel tired and irritated… actually, I feel angry and disappointed…”’) helps distinguishing between subtle emotional experiences [13]. Reappraisal represents a cognitive emotion regulation strategy which consists in rethinking the meaning of affectively charged stimuli or events to decrease their emotional impact. Interestingly, brain-imaging studies of reappraisal consistently show recruitment of ventral portions of the PFC involved in language functions [155]. As shown in Table 6, 8 out of 15 emotion studies (53.3%) reported LIFG activity.
Table 6. Emotion Studies. (P) = Employed PET

| Paper            | Self-task                                                                 | LIFG activation |
|------------------|---------------------------------------------------------------------------|-----------------|
| Critchley et al. | Perceiving (or not) feedback delay of one’s heartbeat (interoception)     | YES             |
| Goldberg et al.  | Evaluating emotional experiences produced by images & music               | YES             |
| Gusnard et al.   | Evaluating one's emotional responses to visual cues                       | YES             |
| Herwig et al.    | See [158]                                                                 | YES             |
| Jackson et al.   | Imagining levels of pain by viewing normal & distorted limbs              | YES             |
| Lane et al.      | See [158]                                                                 | YES             |
| Northoff et al.  | Evaluating degree of self-relatedness to visual cues                      | NO              |
| Ochsner et al.   | See [158]                                                                 | YES             |
| Phan et al.      | Indicating emotional association with pictures                             | NO              |
| Schneider et al. | See [5]                                                                   | NO              |
| Sheline et al.   | Reflecting on current emotional experiences                               | NO              |
| Silani et al.    | See [158]                                                                 | NO              |
| Takahashi et al. | Judging if guilt & embarrassment are present in short sentences           | YES (embarrassment only) |
| Takahashi et al. | Imagining joyful or proud scenarios in response to visual cues            | NO              |
| Taylor et al.    | Rating aversive & nonaversive pictures                                     | NO              |

Table 7. Various self-referential Studies. (P) = Employed PET

| Paper            | Self-task                                                                 | LIFG Activation |
|------------------|---------------------------------------------------------------------------|-----------------|
| Addis et al.     | Pre-experiencing future personal events in response to visual cues        | YES             |
| Arzy et al.      | Indicating if personal events occurred before/after currently imagined self-location in time | YES             |
| Binder et al.    | Resting still with eyes closed                                             | YES             |
| Blackemore et al.| Thinking about intentions & consequential actions in response to presentation of fictive scenarios | NO              |
| Botzung et al.   | See [175]                                                                 | NO              |
| Christoff et al. | See [177]                                                                 | YES             |
| D’Argembeau et al.| Pre-experiencing future personal events in response to visual cues        | NO              |
| D’Argembeau et al.| See [93]                                                                  | YES             |
| Fransson         | See [177]                                                                 | YES             |
| Jenkins & Mitchell| Judging one’s current mental state in response to visual cues              | YES             |
| Johnson et al.   | Choosing which color one prefers                                           | YES             |
| Johnson et al.   | Thinking about hopes & aspirations in response to visual cues             | YES             |
| Longe et al.     | Imagining being self-reassuring/self-critical after negative fictive scenarios | YES             |
| Mazoyer et al.   | See [177]                                                                 | YES             |
| Pan et al.       | Presenting positive, negative & neutral evaluative feedback through visual cues | NO              |
| Paulus & Frank   | Determine which one of two items one prefers                               | NO              |
| Pfeifer et al.   | Making direct/reflected self-appraisals in response to visual cues         | YES             |
| Piech et al.     | Judging if one likes or dislikes food                                     | NO              |
| Seger et al.     | See [188]                                                                 | NO              |
| Spreng & Grady   | See [93]                                                                   | YES             |
| Szpunar et al.   | See [175]                                                                 | NO              |
| Weiler et al.    | See [175]                                                                 | YES             |
| Zysset et al.    | Making evaluative judgments of people                                     | YES             |
3.6. Miscellaneous

Table 3.7 shows that 16 out of 24 miscellaneous studies (66.7%) reported LIFG activation. Studies in this general category included various forms of self-focus such as intentions, hopes, aspirations, mental states, preferences, self-evaluation, and self-location in time. To illustrate, one study invited volunteers to reflect on their intentions in response to the presentation of fictive scenarios [170]. Also included were studies of mental projections of the self into the future (“mental time travel”, “episodic future thinking”, “future-oriented cognition”, “foresight”) [for reviews see 126, 171, 172]. People report producing both mental images and inner speech when engaging in prospection [173]. The role of language in prospection is increasingly being discussed in the literature [e.g., 124, 174]. Our review of brain-imaging studies of prospection is consistent with these ideas. A typical prospection study invites participants to imagine a future personal event in response to the presentation of a visual cue, e.g., a word (“camping”) or a photograph of a tent to stimulate thoughts about a possible future camping trip [see 151]. Phenomenologically speaking, one can propose that such tasks may trigger an internal dialogue such as “I can smell the odor of the tent… It will be fun to wake up early with the sun… Fishing in the creek nearby too will be fun…”

4. CONCLUSION

One major difference between human and non-human animals is that the former possess language and the ability to engage in self-talk [193]. This ability to verbally communicate with the self in turn is assumed to lead to increased cognitive complexity which includes deeper self-referential processing [194]. This paper presented evidence suggesting that inner speech is often used by participants working on various self-reflection tasks. The data show that speech-for-self when thinking about the self is significant, as 55% as all studies reviewed reported LIFG activation, as opposed to 16% in non-self tasks [29]. This conclusion is acceptable only if one embraces the underlying assumption that LIFG activation indicates inner speech use; this assumption is currently supported by neuropsychological and brain-imaging research. Our results also imply a differential involvement of inner speech across self-domains, where reflection on conceptual self-dimensions seems to rely more on verbalization than reflection on perceptual self-aspects. Sixty four percent of studies pertaining to abstract self-domains such as autobiographical memory and personality traits reported LIFG activation, as opposed to 25% of studies of a more perceptual nature.

One limitation of the approach used here is that it remains possible that the activation of the LIFG observed in some studies may reflect other cognitive mechanisms in addition to, or instead of, inner speech use. Although it is possible that LIFG activation underlies semantic processing during some tasks (e.g., personality traits), it is unlikely that the self-tasks described in the Tables require cognitive control, working memory, language unification, selection among competing alternatives, response inhibition, and action understanding.

One hotly debated issue in the literature is the importance of language (and by extension, of inner speech) for ToM [see 195]. Both ToM and most self-reflection tasks involve making inferences about psychological attributes of people—either self or others. Since inner speech seems to play a role in thinking about oneself, it could also constitute the mental activity underlying thinking about others. Indeed, recent work indicates that ToM development is linked to private speech use in preschoolers [196]; also, children with autism (a condition associated with ToM deficits) underuse inner speech [17]. A large quantity of published brain-imaging studies of ToM exists [for a review see 197]. One promising strategy to further test the hypothesis of inner speech involvement in ToM could consist in calculating the percentage of reported LIFG activation across mental state domains e.g., false belief, deceit, intentions, empathy, desires, and pretence.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

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