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Language facilitates introspection: Verbal mind-wandering has privileged access to consciousness

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ABSTRACT

Introspection and language are the cognitive prides of humankind, but their interactions in healthy cognition remain unclear. Episodes of mind-wandering, where personal thoughts often go unnoticed for some time before being introspected, offer a unique opportunity to study the role of language in introspection. In this paper, we show that inner speech facilitates awareness of mind-wandering. In two experiments, we either interfered with verbal working memory, via articulatory suppression (Exp. 1), or entrained it, via presentation of verbal material (Exp. 2), and measured the resulting awareness of mind-wandering. Articulatory suppression decreased the likelihood to spontaneously notice mind-wandering, whereas verbal material increased retrospective awareness of mind-wandering. In addition, an ecological study using smartphones confirmed that inner speech vividness positively predicted mind-wandering awareness (Exp. 3). Together, these findings support the view that inner speech facilitates introspection of one's thoughts, and therefore provides empirical evidence for a positive relation between language and consciousness.

1. Introduction

Two of the most important human cognitive functions, consciousness and language, interact to produce internalized "inner" speech, which is conscious thought with a verbal structure (Alderson-Day & Fernyhough, 2015). Inner speech is reported in 20–30% of daily thoughts (Heavey & Hurlburt, 2008) and has been shown to serve numerous functions related to cognitive control (Cragg & Nation, 2010; Vygotsky, 1962), such as task-monitoring (Tullett & Inzlicht, 2010), task-switching (Emerson & Miyake, 2003) and planning (Lidstone, Meins, & Fernyhough, 2010). Theoretical proposals have suggested that inner speech could also be involved in reflective- and self-awareness (Baumeister & Masicampo, 2010; Morin, 2005; Morin & Everett, 1990). Indeed, task-monitoring, task-switching and planning already rely on the awareness of one's goals. However, empirical evidence for a role for inner speech in awareness is scarce and indirect (Morin & Hamper, 2012).

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Various theories of consciousness (Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006; Lamme, 2006; Lau & Rosenthal, 2011) and meta-cognition (Fleming, Weil, Nagy, Dolan, & Rees, 2010; Kornell, 2009; McCurdy et al., 2013) have recently emerged in parallel to the studies of inner speech. Yet, these theories do not assign any specific role of language in conscious access or metacognitive representations. Whether inner speech increases the salience or awareness of one's own thoughts therefore remains to be tested and integrated to more general models of human consciousness.

The phenomenon of mind-wandering offers a unique opportunity to test how language interacts with consciousness. People often experience thoughts that are not related to the task at hand (Schooler, Reichle, & Halpern, 2004), some of these thoughts having a verbal nature – e.g. wondering, in English, whether a person will show up to an appointment later in the day – and some other thoughts having a imaginal nature – e.g. picturing, with visual mental imagery, that the person will show up or not (Stawarczyk, Cassol, & D'Argembeau, 2013). Moreover, mind-wandering is often unnoticed and people eventually discover that they were zoning out a few seconds after (Schooler et al., 2011). This lack of reflective awareness, or "meta-awareness" (Schooler, 2002; Winkielman & Schooler, 2011), of one's own thoughts is a common failure of introspection: these thoughts are consciously *experienced* – and reportable – yet the ability to take stock of them (i.e. spontaneously noticing them) is temporarily impaired. Two distinct paradigms have been developed to measure mind-wandering awareness. First, the self-caught/probe-caught paradigm (Schooler et al., 2004) holds that episodes of mind-wandering that are reported spontaneously by participants ("self-caught") reflect greater awareness than episodes of mind-wandering that are caught by randomly distributed thought-probes ("probe-caught"). Second, the experience sampling paradigm can include a retrospective assessment by participants of how aware they were of the past mind-wandering episode (Christoff, Gordon, Smallwood, Smith, & Schooler, 2009).

Many factors, such as alcohol intoxication (Sayette, Reichle, & Schooler, 2009), cigarette craving (Sayette, Schooler, & Reichle, 2010), or attention deficit (Franklin et al., 2014) have been shown to impair awareness of mind-wandering. Thus mind-wandering episodes can serve as a test bed for the hypothesis that verbal representations and processing facilitate awareness: we can ask whether participants are more or less aware of their mind-wandering when verbal processing is favored or impaired. We can also ask whether the verbal phenomenology of one's mind-wandering thought is associated with increased awareness.

In this paper, we present three studies showing that verbal processing contributes to the awareness of mind-wandering, as measured either by the self-caught/probe caught (Exp. 1) or the experience sampling paradigms (Exp. 2 & 3). First, in two laboratory experiments, we tested whether the amount of verbal material in mind-wandering episodes predicted whether participants were aware of them. We used articulatory suppression (RepovŠ & Baddeley, 2006) to decrease the verbal content of working memory (Exp. 1), and we presented verbal material (Abramson & Goldinger, 1997; Pintner, 1913) so as to entrain the verbal component of working memory (Exp. 2). In addition, a crowd-sourced study running on Android smartphones was designed to test whether more vivid verbal thoughts were positively associated with heightened awareness.

2. Experiment 1

Experiment 1 tested whether the impairment of verbal working memory decreases awareness of mind-wandering. Articulatory suppression was used to impair verbal working memory, and mind-wandering awareness was measured using the self-caught/probe-caught paradigm.

2.1. Material and methods

2.1.1. Participants

29 students (15 females, 21.5 y.o., SD = 4.4, range = [18–39]) from the Department of Psychology of the University of California, Santa Barbara (UCSB) participated in the study. All participants had normal or corrected-to-normal vision and spoke fluent English.

2.1.2. Materials

2.1.2.1. Primary task. A version of the SART (Sustained Attention to Response Task, Robertson, Manly, Andrade, Baddeley, & Yiend, 1997) was used as the base task, with thought-probes (Hurlburt & Heavey, 2004; Klinger, 1978) to measure mind-wandering and meta-awareness. Digits were presented sequentially in white "courier new" font (30 points) at the center of a black computer screen (refresh rate of 60 Hz) for 500 ms, every 2 s. Participants were required to press the space bar as fast as possible in response to each digit except when presented with the digit "3" (the target no-go stimulus). No-go targets were rare (7%: 8 out of 108 trials per block).

2.1.2.2. Secondary task. The SART was performed under three conditions in a within participant design: (1) single-task (hereafter ST) (2) articulatory suppression dual-task (hereafter AS), and (3) foot tapping control dual-task (hereafter FT). In the articulatory suppression condition, participants repeated "a-b-c" out loud, while in the foot tapping condition they tapped on a stapler fixed on the floor. The rhythm for both articulatory suppression and foot tapping conditions was one beat every 750 ms, as set by a metronome at the beginning of each block. The disruptive effects of both foot tapping and articulatory suppression have been shown to be comparable (Emerson & Miyake, 2003; Gaillard, Destrebecqz, & Cleeremans, 2012; Miyake, Emerson, Padilla, & Ahn, 2004).

2.1.2.3. Thought-reports. We used the self-caught/probe-caught paradigm (Schooler et al., 2011; Smallwood & Schooler, 2006) to collect thought-reports and assess meta-awareness. Participants were instructed to press "Enter" on the keyboard to spontaneously report – self-catch – off-task thoughts whenever they noticed one. Moreover, four thought-probes randomly interrupted each of the six blocks. Following previous literature (Baird, Smallwood, Fishman, Mrazek, & Schooler, 2013; Sayette et al., 2009, 2010; Schooler et al., 2004), the percentage of probe-caught mind-wandering was taken to reflect the baseline experience of mind-wandering, while the number of self-caught mind-wandering was taken to reflect specifically meta-aware episodes of mind-wandering. Participants responded to the probes with Likert and categorical scales, in a fixed order: first, participants reported "how focused they were on the task" using a 5-point Likert scale ranging from 1: "On-Task" to 5: "Off-Task". Instructions explicitly related "Off-Task" to daydreaming and mind-wandering, and we did so before participants engaged in the SART. Second, participants reported how aware they were of their last thought on a 5-point Likert scale. Critically, instructions stressed that this second scale was independent from the first. Next, participants described the phenomenology of their last thought as: (1) Inner Speech: i.e. talking to oneself in one's mind using words that one would have been able to report, (2) Imagery: i.e. having the visual experience of a mental image (3) Other: experiencing neither inner speech or imagery, or failing to introspect. Participants could combine these categories to report complex subjective experiences. Finally, a fourth question asked about the time orientation of the thought. This last question was collected for a different project and was not analyzed for this study.

2.1.2.4. Spontaneous reports. Self-caught reports of mind-wandering only featured the imagery/verbal and temporal orientation scales, as they were by construction aware mind-wandering episodes.

2.1.3. Procedure

Participants were tested individually in a quiet, dimly-lit room. Training consisted of three blocks (one per condition, in random order) of 24 SART trials each. Testing consisted in six experimental blocks (two per condition) of 108 trials each, in the absence of the experimenter. Block order was pseudo-randomized so that two blocks of the same condition could not directly follow each other. The experimental session lasted around 29 min (SD = 3, range = [20–40]) depending on (1) the durations of metronome adjustments, (2) participants' propensity to make spontaneous reports, and (3) participant's speed in categorizing their thoughts. After the experimental session, participants were debriefed, and paid 10 USD or given course credits.

2.1.3.1. Cover story and incentive. The experiment was presented as a test of the participant's ability to keep a rhythm while engaged in an attention task. Each participant was audio recorded during the experiment, as an explicit incentive to perform the dual task correctly. This was used as an off-line check for compliance with instructions. Note that after each interruption for thought reports, the metronome was used to reset the rhythm of the dual task.

2.2. Results

Data analysis was performed with *R* (R Core Team, 2014) with the *lme4* (Bates, Mächler, Bolker, & Walker, 2014) package for mixed models. All regressions are mixed models with participants as a random factor. Four participants were excluded due to noncompliance on the dual task.

First, we assessed the effect of the experimental conditions on the SART. As can be seen in Table 1, response times on correct go trials in the single-task were faster than in the two dual tasks ($ps < 0.001$), suggestive of a dual task cost. We also observed a speed-accuracy trade-off in the foot tapping condition which was the slowest on correct go trials (all $ps < 0.001$) and the most accurate on no-go trials, compared to both the articulatory suppression ($\beta = 0.45$, SE = 0.16, $z = 2.90$, $p < 0.01$) and single-task ($\beta = 0.32 \pm 0.15$, $z = 2.10$, $p < 0.05$, AS/ST: $p > 0.4$). This suggests more controlled processing in the foot tapping than in the two other conditions. Yet, a signal-detection approach on SART performance (see McVay, Meier, Touron, & Kane, 2013 for details) did not evidence any significant effect of conditions on neither d-prime nor criterion (individual hit or false-alarm rates of 0 and 1 adjusted by 0.001.). As such, although processing might have been more controlled in the foot tapping condition, processing quality remained comparable across conditions.

Second, we analyzed reports of mind-wandering from external probes, considering them as a baseline (Sayette et al., 2009, 2010). To do so, we binned reports on the mind-wandering scale (<3 categorized as "On-task" (N = 401), $\geqslant 3$ "Off-task" (N = 252)), so as to create a binary mind-wandering variable. Percentage of mind-wandering were 37.56% (ST), 39.51% (FT), and 33.67% (AS). Logistic regressions on the likelihood to report mind-wandering did not reveal a significant effect of condition ($\chi^2(2) = 3.23$, $p = 0.20$), suggesting that our experimental manipulation did not impact participants' proneness to mind-wander.

wNext, we tested whether awareness of mind-wandering episodes was modulated by our experimental conditions. Crucially, a Poisson regression for count data revealed that participants were less likely to self-catch mind-wandering under articulatory suppression (mean spontaneous reports = 1.96, SE = 0.55) than in the single-task (3.04 ± 0.73, $\beta = -0.44 \pm 0.18$, $z = -2.40$, $p < 0.05$) or the foot tapping conditions (3.00 ± 0.66, $\beta = -0.43 \pm 0.18$, $z = -2.32$, $p < 0.05$, difference ST/FT: $p > 0.9$, Fig. 1a).

The awareness scale of external probes led to similar, albeit non-significant results. Indeed, a binary index of awareness (excluding middle value) of mind-wandering evidenced the lowest index of awareness in the articulatory suppression condition (53.58% aware) compared to the foot tapping (58.90%) and single-task conditions (61.75%, overall effect of condition: $p > 0.9$).

Table 1
Effects of conditions (Exp. 1). Response Times (RT) were significantly different in each condition (all $ps < 0.001$), and foot tapping increased accuracy compared to both AS ($p < 0.01$) and ST conditions ($p < 0.05$; AS/ST: $p > 0.4$). Retrospective scales evidenced no significant differences in mind-wandering amount, mind-wandering awareness nor inner speech proportion. Crucially, the number of spontaneous reports significantly decreased in the AS condition compared to both ST ($p < 0.05$) and FT conditions ($p < 0.05$, ST/FT: $p > 0.9$). In parentheses are the standard deviations.

Measure\condition	Single-task	Foot tapping	Artic. Supp.	p-value
Median RT go trials (ms, RT > 50 ms)	367 (± 44)	445 (± 85)	394 (± 52)	***
Accuracy no-go (% correct)	42.21 (± 24.16)	48.19 (± 24.85)	39.92 (± 21.39)	**
D-prime on SART	4.76 (± 3.18)	4.74 (± 2.59)	4.58 (± 2.14)	ns
Criterion on SART	−3.11 (± 0.92)	−2.63 (± 1.03)	−3.02 (± 1.05)	ns
Mind-wandering (mid-scale as MW, %)	37.56 (± 28.82)	39.51 (± 27.37)	33.67 (± 21.96)	ns
Awareness in MW (mid-scale excluded, %)	61.75 (± 41.07)	58.90 (± 35.49)	53.58 (± 41.28)	ns
Inner speech (%)	31.97 (± 23.91)	30.53 (± 29.25)	22.89 (± 20.29)	ns
Number of spontaneous reports	3.04 (± 3.65)	3.00 (± 3.32)	1.96 (± 2.76)	***

* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

Regarding phenomenology, the proportion of inner speech across spontaneous and external reports of mind-wandering did not significantly differ across conditions (overall effect of condition $p > 0.3$), although it was reported to be lowest in the articulatory suppression condition (22.89% vs. 31.97% in single-task and 30.53% in foot tapping). Along a similar line, proportion of visual imagery was *higher* in articulatory suppression (43.37, SE = 6.11%) than in both single-task (38.70 ± 5.49%) and foot tapping condition (32.47 ± 5.61%), this latter difference being significant ($\beta = -0.71 \pm 0.26$, $z = -2.74$, $p < 0.01$, ST/AS: $\beta = -0.36 \pm 0.25$, $z = -1.44$, $p = 0.15$).

Finally, self-caught reports, compared to probe-caught reports of mind-wandering, were significantly more verbal (36.20 ± 4.98% vs. 18.41 ± 4.23%, $\beta = 1.08 \pm 0.25$, $z = 4.37$, $p < 0.001$, Fig. 1b), less imaged (33.25 ± 5.43% vs. 37.39 ± 4.60%, $\beta = -0.53 \pm 0.24$, $z = -2.23$, $p < 0.05$) and less abstract (strict 'Else' response: 33.33 ± 7.54 vs. 44.92 ± 6.64%, $\beta = -0.80 \pm 0.26$, $z = -3.09$, $p < 0.01$). This suggests that the *verbal* content of self-caught mind-wandering episodes made them more vivid, though less imaged.

2.3. Discussion

Experiment 1 presents evidence that articulatory suppression, compared to single- and control dual-task conditions, decreased the number of spontaneous reports of mind-wandering, which is a common index of meta-awareness of mind-wandering (Baird et al., 2013; Sayette et al., 2009, 2010; Schooler et al., 2011, 2004). Moreover, these self-caught episodes of mind-wandering were reported to be more verbal than probe-caught episodes of mind-wandering, which, by definition are less aware. This pattern of findings shows that interfering with verbal working memory can be detrimental to mind-wandering awareness and thus suggests that inner speech participates in access to mind-wandering.

These conclusions are further supported by the absence of significant change across conditions in the likelihood to report mind-wandering on external thought-probes, thus suggesting that baseline experience of mind-wandering remained unaffected by experimental conditions. However, the present experiment did not evidence significant decreases in retrospective assessment of inner speech, across experimental conditions. We speculate that the production of a vocal stream in the AS condition made it more difficult for participants to assess whether they were *thinking* verbally or not.

3. Experiment 2

Experiment 1 showed that we could decrease awareness of mind-wandering. By contrast, Experiment 2 aimed at showing that we could *increase* awareness of mind-wandering. Experiment 2 was also designed as a more implicit manipulation of verbal working memory than articulatory suppression, and without the dual tasking paradigm that might have consumed resources. We reasoned that, given that reading automatically involves inner speech (Abramson & Goldinger, 1997; Pintner, 1913), increasing participants' exposition to verbal material would increase their activation of verbal working memory. More precisely, our manipulation would consist in *intermittent priming* of verbal working memory to greater or lesser extends, from 1.5 to 3 s within ten seconds. Thus we predicted that such priming of verbal working memory would increase meta-awareness of mind-wandering, here measured exclusively with the experience sampling paradigm.

3.1. Material and methods

3.1.1. Participants

24 participants (17 females, 23.1 y.o. ±3.9, [18–34]) were recruited from the listings of the LSCP, Paris. All had normal or corrected-to-normal vision and were paid 10 euros, for a one hour session.

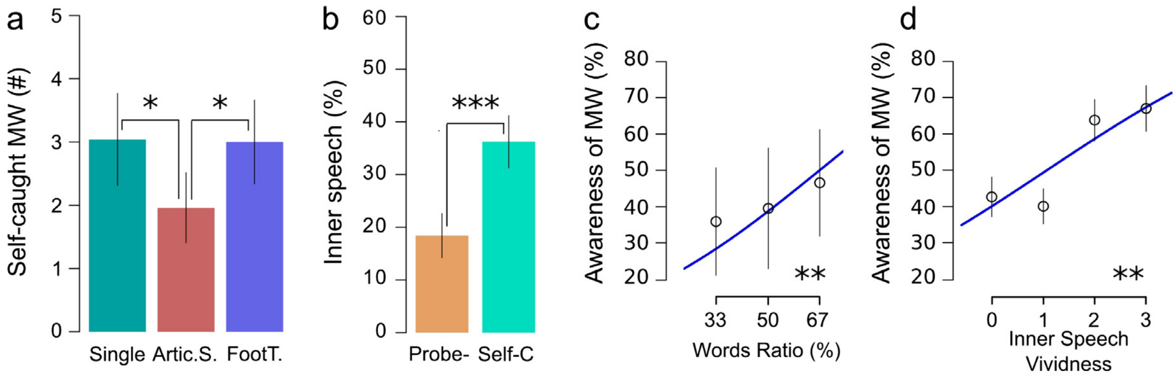

Fig. 1. Results. (a) Exp. 1: Articulatory suppression decreased the number of self-caught reports of mind-wandering compared to the two control conditions. (b) Exp. 1: Self-caught reports of mind-wandering were more verbal than probe-caught reports of mind-wandering. (c) Exp. 2: Awareness of mind-wandering increased with the ratio of words to pictures among SART stimuli. (d) Exp. 3: Awareness of mind-wandering increased with inner speech vividness in an ecological smartphone-based study. Abbreviations: Artic.S.: articulatory suppression, FootT: foot tapping, Probe-: Probe-caught reports of mind-wandering, Self-C: Self-caught reports of mind-wandering.

3.1.2. Materials

3.1.2.1. Task. The SART was adapted so as to present concepts, in words or pictures. Stimuli were presented for 1.5 s every 3.5 s. Participants were required to press the space bar as fast as possible in response to each stimulus but to withhold their response when presented with one no-go target concept, randomly picked for each participants. 12 concepts were used: 3 categories (animal/object/scene) $\times$ 2 familiarities (high/low) $\times$ 2 instances---for example we had 2 concepts for highly familiar animals: "dog" and "cat", see Appendix 1 for the complete table of stimuli. Furthermore, for each concept, there were 4 exemplars: 2 words (lowercase/uppercase, Arial, 20) and 2 different pictures. This combination of conditions resulted in a set of 48 items, 4 of which (e.g. "DOG", "dog", Dog-Picture1 and Dog-Picture2) were designated for a given participant as no-go targets (8.3%).

3.1.2.2. Pictures. A set of 24 colored pictures of 256 $\times$ 256 pixels were selected from Brady and colleagues' (Brady, Konkle, Alvarez, & Oliva, 2008) stimuli base, representing twelve concepts (eg. dog, street, clock).

3.1.2.3. Word/Picture-Ratio. Each participant was presented with a seamless experiment, divided in three blocks of equal length. Six repetitions of the two exemplars of each of the twelve concepts composed the 144 trials (including the 12 targets) of each block. The three blocks differed with respect to their word/picture-ratio, which was 33%, 50% and 67%. This ratio was the critical condition for this experiment. Block order was randomized between participant. Given the small percentages difference, the randomization of pictures and words within blocks, and the absence of any explicit demarcation between blocks, our experimental conditions were anticipated to be implicit.

3.1.2.4. Thought-reports. Twelve pseudo-randomly distributed external probes interrupted the task in each block: 6 immediately following picture-stimuli and 6 immediately following word-stimuli (regardless of the type of block). This controlled for priming by the immediately preceding stimulus. Mind-wandering and meta-awareness scales were 5 grades Likert scales identical to the ones of Experiment 1. Similarly, the time orientation scale was identical to Experiment 1, and was again not analyzed. However, questions about phenomenology now provided six possibilities (Heavey & Hurlburt, 2008): (1) inner speech (2) visual imagery, (3) auditory imagery (e.g. having a tune in mind), (4) bodily sensation: focus on one's body, (5) emotion: focus on a particular emotion (e.g. sadness), (6) other: thought that was neither in words, images, sounds, and not even a sensation or an emotion. This last category could also be chosen when participants could not successfully introspect the form of their thought. As opposed to Experiment 1, these possibilities were mutually exclusive and participants had to report the most salient and obvious phenomenology. This was justified by the fact that in Experiment 1, only 14 of the 1010 thought-reports (< 1.5%) were mixed forms thoughts. There was no spontaneous reports in this experiment: awareness was exclusively measured with the awareness scale.

3.1.2.5. Short version of the Individual Difference Questionnaire (IDQ). Participants' imaginal and verbal thinking habits and skills (i.e. "cognitive styles") were measured with the "verbal habits" and "imaging habits" subscales of the French version (Grebot, 2000) of the Individual Differences Questionnaire (Paivio & Harshman, 1983).

3.1.3. Procedure

Participants first performed a training session of 20 trials (2 no-go targets and 2 external probes). Then they completed the main experiment, which, depending on their speed in classifying their thoughts lasted 30 to 45 min. Debriefing questions targeted at the implicitness of the manipulation and the short IDQ was then administered.

Table 2
Effects of conditions (Exp. 2). Word-ratio did not significantly affect RT, accuracy, mind-wandering or inner speech, but did increase mind-wandering awareness ($p < .01$). In parentheses are the standard deviations.

Measures\word-ratio	33%	50%	67%	p-value
Median RT go trials (ms, RT > 50 ms)	662 (156)	650 (162)	656 (142)	ns
Accuracy no-go (% correct)	91.00 (11.24)	86.86 (10.67)	87.23 (12.45)	ns
D-prime on SART	10.09 (2.71)	9.17 (2.55)	9.39 (2.98)	ns
Criterion on SART	−1.07 (1.44)	−1.61 (1.32)	−1.20 (1.53)	ns
Mind-wandering (mid-scale as MW, %)	59.03 (24.93)	57.99 (23.25)	59.03 (24.56)	ns
Awareness in MW (mid-scale AW excluded, %)	36.06 (36.12)	39.68 (40.42)	46.69 (35.81)	**
Inner speech (%)	30.20 (26.49)	32.66 (27.44)	29.98 (25.48)	ns

* $p < .05$.
** $p < .01$.
*** $p < .001$.

3.2. Results

Debriefing revealed that no participant identified the manipulation of word/picture-ratio. Analyses were therefore conducted on the 24 participants.

Performances on the SART are presented in Table 2. We found no significant effect of block on performance. To test whether the likelihood to report mind-wandering was modulated across blocks, we binned reports on the mind-wandering scale (<3 categorized as "On-task" (N = 357), ⩾3 "Off-task" (N = 504)). A logistic regression with percentage of words as predictor did not reveal any significant effect of the percentage of words on the proportion of mind-wandering (59.03, 57.99 and 59.03% with respectively 33, 50 and 67% words, $p > 0.9$).

Next, we tested whether awareness of mind-wandering was modulated by the proportion of word in a block. The 504 mind-wandering reports were binned along the awareness scale (<3 categorized as "aware" (N = 166), >3 "unaware" (N = 261); excluding 77 mid-scale reports). As predicted, a logistic regression revealed that mind-wandering awareness significantly increased with proportion of words (36.0, 39.7 and 46.7% in 33, 50 and 67% words blocks, $\beta = 2.73 \pm 1.00$, $z = 2.73$, $p < 0.01$, Fig. 1c).

Further analyses on the likelihood to report verbal thoughts when mind-wandering revealed no significant effect of word-ratio ($p > 0.7$), meta-aware mind-wandering were not significantly more verbal than unaware mind-wandering (26.04 + 6.80 vs. 28.53 + 5.16, p > 0.6), and there was no significant correlation at the inter-individual level between awareness of mind-wandering and verbal ($p > 0.9$) or imaging ($p > 0.2$) cognitive styles (IDQ questionnaire).

3.3. Discussion

Experiment 2 found that, while an implicit manipulation of the amount of verbal processing did not affect performance nor the amount of mind-wandering, it did increase awareness of mind-wandering. Indeed, awareness of mind-wandering as assessed with external probes increased with increased proportion of words in a block. Given that in each block, half of the thought-probes were presented after a picture and half after a word, this effect cannot be due to the local priming from the immediately preceding stimulus, but instead to a contextual effect at the level of the block. Moreover, unlike Experiment 1, the critical manipulation was implicit, ruling out any explanation coming from the demand characteristics of the task.

Previous studies have reported effects of sensory stimuli on the temporal orientation of mind-wandering (Miles, Karpinska, Lumsden, & Macrae, 2010; Smallwood, Nind, & O'Connor, 2009) but, to our knowledge, this experiment is the first to show that on-line first-order processing can impact awareness of mind-wandering.

We did not find an effect of word-ratio on reported inner speech. To decipher whether this was truly due to a lack of awareness of the role of verbal working memory in mind-wandering awareness, we designed Experiment 3 as a crowd-sourced ecological study.

4. Experiment 3

Experiment 3 was a crowd-sourced ecological study using a smartphone application to probe participants in their natural environment, without any experimental manipulation. Questions about phenomenology were refined, so as to quantify thoughts' verbal, visual and auditory vividness independently from each other. We predicted that verbal vividness would positively correlate with awareness of mind-wandering as measured exclusively with experience sampling, while visual or auditory vividness would not.

4.1. Material and methods

4.1.1. Participants

We designed an application, *Daydreaming* (http://daydreaming-the-app.net/), running on Android smartphones, so as to conduct an *in-situ* experience sampling study (Heavey & Hurlburt, 2008): the main function of the application was to trigger probes at random moments during the day, and to provide scales so that participants could report their current mental state. Promotion of the application was made via social networks and oral presentations. Promotion never mentioned the hypothesized relation between inner speech and mind-wandering awareness, and made clear that the application had a research goal.

On October 10th, 2015, 159 users had interacted with the application at least once. Here, the between-individual relations between questionnaires and probe answers, and the within-individual relation between thought vividness and mind-wandering is based on the data of the 90 participants (54 females, mean age: 28.8, SD = 9.9, range = [18, 60–69]) who filled all four questionnaires upon downloading the application (see below) and completed at least two random probes (max = 142, median = 11, mean = 21.3, SD = 24.5 per participant). Scores less than or equal to the middle mind-wandering scale were considered as mind-wandering reports (846 out of 1915 probes). The analysis on the relation between thought vividness and awareness of mind-wandering is based on the data of the 69 participants (39 females, age = 29.2 ± 9.9, range = [18, 50–59]) who reported mind-wandering at least twice, and whose mind-wandering reports included a mind-wandering awareness judgment (total: 744 probes, and per participant: max = 142, median = 17, mean = 26.2, SD = 26.0).

4.1.2. Methods

The code for the android application can be found online at the following Github repository: https://github.com/daydreaming-experiment. Three different types of interactions, all in English, were proposed by the *Daydreaming* application.

4.1.2.1. Begin/end questionnaires. First, upon downloading the application, participants were required to fill three standardized questionnaires: the Mindful Attention Awareness Scale (Brown & Ryan, 2003) assessing one's propensity to be mindful in daily life, the Scale Of Dissociative Activities (Mayer & Farmer, 2003) assessing non pathological and daily tendencies to be dissociated, and the Rumination-Reflection Questionnaire (Trapnell & Campbell, 1999) composed of two subscales: daily amounts of ruminations, and propensity to reflect on oneself. These three questionnaires were also proposed at the end of the 30-days study.

4.1.2.2. Morning/evening questionnaires. Second, three questions appeared on the application every morning, asking about sleep duration, dreams vividness, and valence of dreams. Two questions appeared every evening, asking about overall happiness and amount of automatic pilot sensation during the day, and about the duration of various daily activities.

4.1.2.3. Random thought-probes. Crucially, participants were randomly probed during the day. Random notifications were triggered every 2 h on average. If the probe was not completed, the notification disappeared and was reprogrammed. Probes asked about the context (location, number of people around, type of noise) and type of activity participants were engaged in. Five questions were critical to probe mental content: (1) "How focused were you on what you were doing?", on a 5 points scale: "My mind was totally wandering; My mind was mostly wandering; My mind was both focused & wandering; My mind was mostly focused; My mind was totally focused", (2) "How meta-aware were you of your mind-wandering?", 4 points scales: "Not aware at all of my mind-wandering; The phone might have helped me notice; I knew I was mind-wandering somehow; I knew explicitly I was mind-wandering", (3) "Were you thinking in words?", 4 points: "Not at all; In some abstract way; With some precise words; In clear and precise words", (4) "Were you thinking with visual images?" 4 points: "Not at all; In some abstract way; With some visual features; With vivid images", (5) "Were you thinking with sounds?" 4 points scale: "Not at all; In some abstract way; With some acoustic features; With vivid sounds". Participants were also asked (6) "How aware were you of your surroundings?", and (7) "Who were you thinking about?".

These seven questions appeared on the same screen, in random order, with the exception that the awareness of mind-wandering question immediately followed the mind-wandering question. All subjective questions featured a "I don't know" button. For questions about thought vividness, these responses were taken as a "Not at all". For the mind-wandering awareness question, answering "I don't know" excluded the probe from the awareness analysis. Full completion of the thought-probe lasted less than 1 min. All questionnaires and most of the non-subjective questions were collected for a different project. Here, we analyze only data pertaining to the relations between mind-wandering, mind-wandering awareness and verbal, visual and auditory vividness.

4.1.3. Procedure

Volunteers downloaded the application from the Google Play store. After participating for 30 days and responding to 10 probes at least, a detailed synthesis of the participant's own results was displayed on the application as a token for his/her participation.

4.2. Results

Table 3 presents the inter-individual correlations between personality questionnaires filled at the beginning of the experiment (MAAS, SODAS and Rumination and Reflection subscales of the RR) and the probe responses averaged by individual. There were significant correlations between three of the four scales: SODAS and Rumination positively correlated together ($r = 0.47$) and both negatively correlated with the MAAS ($r = -0.69$, $r = -0.49$ respectively). None of these questionnaires correlated with the Reflection subscale, confirming that one's interest in reflecting on one's life is independent from one's propensity for rumination, mindfulness or being dissociated. Interestingly, the MAAS and the SODAS were also the only pre-

Table 3
Inter-individual correlations (Exp. 3). Each participant completed mindfulness (MAAS), dissociation (SODAS), rumination (RR-rumination subscale) and reflection (RR-reflection subscale) questionnaires upon downloading the application. The profiles of those who also responded to at least two probes (N = 90) were correlated with their awareness of their surroundings and mind-wandering answers to those probes. The last line correlates awareness of mind-wandering to the profiles of the participants who answered at least two times that they were mind-wandering (N = 69). Abbreviations: MAAS: Mindful Attention Awareness Scale; SODAS: Scale Of Dissociative Activities; MW: mind-wandering.

	# of Probes answered	1	2	3	4	5	6
1. MAAS	0.227*	–					
2. SODAS	−0.239*	−0.690***	–				
3. Rumination	−0.153	−0.488***	0.465***	–			
4. Reflection	0.025	−0.086	0.071	0.079	–		
5. Awareness of Surroundings	−0.139	0.290**	−0.211*	0.123	−0.127	–	
6. Mind-wander ing propensity	0.028	−0.294**	0.378***	0.115	0.031	−0.284**	–
7. Awareness of MW (69 prtcp.)	−0.164	0.119	0.018	−0.011	−0.077	.341**	0.028

* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

dictors of the number of probes answered by participant: the more mindful (r = 0.23) and the less dissociate people (r = −0.24) answered more probes. Moreover, both MAAS and SODAS correlated with mind-wandering and awareness of the surroundings: more mindful, or less dissociated people had lesser mind-wandering (r = −0.29, r = 0.38) and greater awareness of their environment (r = 0.29, r = −0.21). Finally, within experience sampling measures, people with high awareness of the surroundings tended to have high awareness of mind-wandering too (r = 0.43), but also lower amounts of mind-wandering (r = −0.28), confirming that on the contrary high mind-wanderers tend to be less aware of their environment because a state of perceptual decoupling confirmed at a probe level (over 1745 probes, N = 90, logistic regression on the likelihood to be mind-wandering predicted by awareness of the surroundings: β = −0.65, SE = 0.13, z = −4.98, p < 0.001). Overall, these correlations between questionnaires on daily thinking habits and experience sampling measures are consistent with the literature on mindful awareness and mind-wandering (Brown & Ryan, 2003; Mrazek, Smallwood, & Schooler, 2012; Schooler et al., 2011) and thus confirm the validity of the collected data.

Turning to within-individual variability, we first aimed at identifying the specific phenomenology of mind-wandering: when someone reports mind-wandering, what else is she likely to report at the same moment? A logistic regression with verbal, visual and auditory vividness as predictors evidenced that both visual vividness (β = 0.21 ± 0.08, $z = 2.65$, $p < 0.01$) and auditory vividness (β = 0.19 ± 0.08, $z = 2.26$, $p < 0.05$) predicted mind-wandering: visual imagery was greater in mind-wandering (1.33, SE = 0.10, scale from 0 to 3) than in focused attention (1.05 ± 0.09); and so was auditory imagery (0.76 ± 0.08 vs. 0.70 ± 0.09). On the contrary, inner speech vividness did not significantly predict mind-wandering (β = −0.08, $p > 0.4$).

Finally, among mind-wandering responses, the awareness question was binarized so as to consider "I somehow knew . . ." and "I knew explicitly" answers as reflecting aware mind-wandering. We regressed likelihood to be aware of mind-wandering episodes on verbal, visual and auditory vividness as predictors and found that only inner speech vividness was a significant predictor of awareness (β = 0.35 ± 0.11, $z = 3.07$, $p < 0.01$, Fig. 1d): inner speech was more intense in aware (1.55 ± 0.10, scale from 0 to 3) than unaware mind-wandering (1.04 ± 0.10). However, neither visual (β = 0.10, $p > .35$) nor auditory vividness (β = 0.23, $p > 0.10$) predicted mind-wandering awareness. Indeed, model comparison between a model with verbal vividness as the only predictor of mind-wandering awareness and a more complex model including verbal, visual and auditory vividness as predictors evidenced no significant improvement for the more complex model ($AIC_{simple\_model} = 977.9$ vs. $AIC_{complex\_model} = 979.1$, $\chi^2(2) = 2.84$, $p = 0.24$), showing that only inner speech vividness predicted awareness of mind-wandering.

4.3. Discussion

Experiment 3 provides further evidence of a positive relation between inner speech and awareness of mind-wandering. Reports from participants consistently related inner speech vividness to their awareness of mind-wandering, while visual and auditory vividness did not predict awareness. Thus, this effect cannot be accounted for by a non-specific effect of vividness.

Moreover, visual vividness was shown to predict the likelihood to report mind-wandering, as mind-wandering was significantly more visual than focused attention. Beyond demonstrating the sensitivity of the visual vividness measure, this also confirms previous suggestions that most mind-wandering involves mental imagery (Smallwood, O'Connor, Sudberry, Haskell, & Ballantyne, 2004). It has been found in functional brain imaging study that on-task thoughts are more similar to mind-wandering with awareness than to mind-wandering without awareness (Christoff et al., 2009). Our results suggest that this may be due to the fact that the latter is intrinsically less verbal than on-task thoughts and aware mind-wandering thoughts.

Finally, the convergence of the results of Experiment 3 and of Experiments 1–2 suggests that the role of inner speech in awareness is ubiquitous. However we acknowledge the need of further work to confirm that the introspective mechanisms observed in the laboratory are the same than those spontaneously engaged in daily life, when mind-wandering is to be detected.

5. General discussion

The hypothesis that inner speech facilitates awareness of mind-wandering was tested in three experiments. Experiment 1 showed that articulatory suppression, known to interfere with verbal working memory, decreased the likelihood of spontaneously noticing one's mind-wandering. Moreover, self-caught mind-wandering episodes, which are by definition aware episodes, were also reported to be more verbal than probe-caught reports of mind-wandering. Conversely, Experiment 2 showed that increased activation of verbal working memory increased awareness of mind-wandering. Finally, Experiment 3 observed that the awareness of mind-wandering reports made on smartphones during participants' daily life positively correlated with inner speech vividness, to the exclusion of visual or auditory vividness. Together, these findings support the hypothesis that inner speech, unlike visual or auditory imagery, facilitates awareness of mind-wandering.

Our study suggests new lines of research on introspection. Showing that the introspective capacity to notice one's mind-wandering relates to its verbal content, the present study provides, to our knowledge, the first experimental evidence in favor of the recently proposed view that consciousness serves cultural purposes such as sharing experiences and thoughts (Baumeister & Masicampo, 2010). Future research should explore whether this positive role of inner speech extends to the introspection of other mental contents. For instance, decreased amounts of inner speech could index psychological absorption and ''flow'' states (Dietrich, 2004; Nakamura & Csikszentmihalyi, 2002), or immersive experiences such as hypnosis (Demertzi et al., 2011). Similarly, the extent to which other forms of meta-cognition, such as confidence estimation (Fleming, Huijgen, & Dolan, 2012), subjective estimations of time (Miller, Vieweg, Kruize, & McLea, 2010; Wittmann, 2013), or feeling of knowing (Reder & Ritter, 1992) also involve inner speech should also be further tested. Importantly, the recent proposal that confidence judgments are instrumental in successful co-operation (Bahrami et al., 2010; Shea et al., 2014) also rests on the assumption that confidence in individual decisions are exchanged verbally. Our finding that access to our attentional states is facilitated by their verbal content, suggests that this may depend on confidence being, at first, internally expressed as inner speech.

These relations between awareness of mind-wandering and inner speech raise intriguing speculations about their neurocognitive underpinnings. Both the frontopolar (Brodmann area 10) and frontoinsular cortices have been related to human awareness. The frontopolar cortex is involved in meta-cognition (Fleming et al., 2012), awareness of one's thoughts (McCaig, Dixon, Keramatian, Liu, & Christoff, 2011) and mindfulness (Fox et al., 2012). The frontoinsular cortex is involved in mindfulness (Tang et al., 2009), the awareness of mind-wandering (Christoff et al., 2009; Hasenkamp, Wilson-Mendenhall, Duncan, & Barsalou, 2012) and interoceptive awareness (Craig, 2009). Now notably, the left frontoinsular cortex is also involved in inner speech and auditory hallucinations (Mcguire et al., 1996). Furthermore, a recent meta-analysis of brain activity during self-referential tasks, which activates both frontopolar and frontoinsular cortices, also evidenced significant activity in the left inferior frontal gyrus (Morin & Hamper, 2012), which is a key region in inner speech (Geva et al., 2011; Marvel & Desmond, 2012). Finally, both frontopolar and frontoinsular cortices differ in humans compared to non-human primates, these latter lacking a language faculty (Premack, 2007). First, these two cortices present more, and larger ''spindle neurons'' – also termed Von Economo Neurons (VEN) – in human than in ape brains (Premack, 2007; Semendeferi, Armstrong, Schleicher, Zilles, & Van Hoesen, 2001). Second, the human frontopolar and frontoinsular cortices constitute a network of VEN (Cauda et al., 2013), which is more connected than in the chimpanzee's brain (Spocter et al., 2012). Given this neurobiological architecture, our study suggests human introspection may rely on the strong and human-specific within-connectivity of the frontal cortex to integrate information between language area, the fontopolar and frontoinsular cortices.

In conclusion, while we show a role of inner speech in the meta-awareness of mind-wandering, the functional mechanisms are still to be further described. A first hypothesis would be that inner speech is salient to introspection, as speech and language are to perception (Jiang, Costello, & He, 2007; Yang & Yeh, 2011). A verbal thought would therefore more easily reach awareness than other mental contents. That inner speech vividness correlates with mind-wandering awareness (Exp. 3) provides evidence for this hypothesis. Yet, inner speech could also belong to the machinery of noticing one's thoughts (Carruthers, 2002). Along this line, inner speech should be conceived as an active tool for consciousness. Addressing these questions in further detail would clarify the relations between two of the most human cognitive characteristics: language and reflective awareness.

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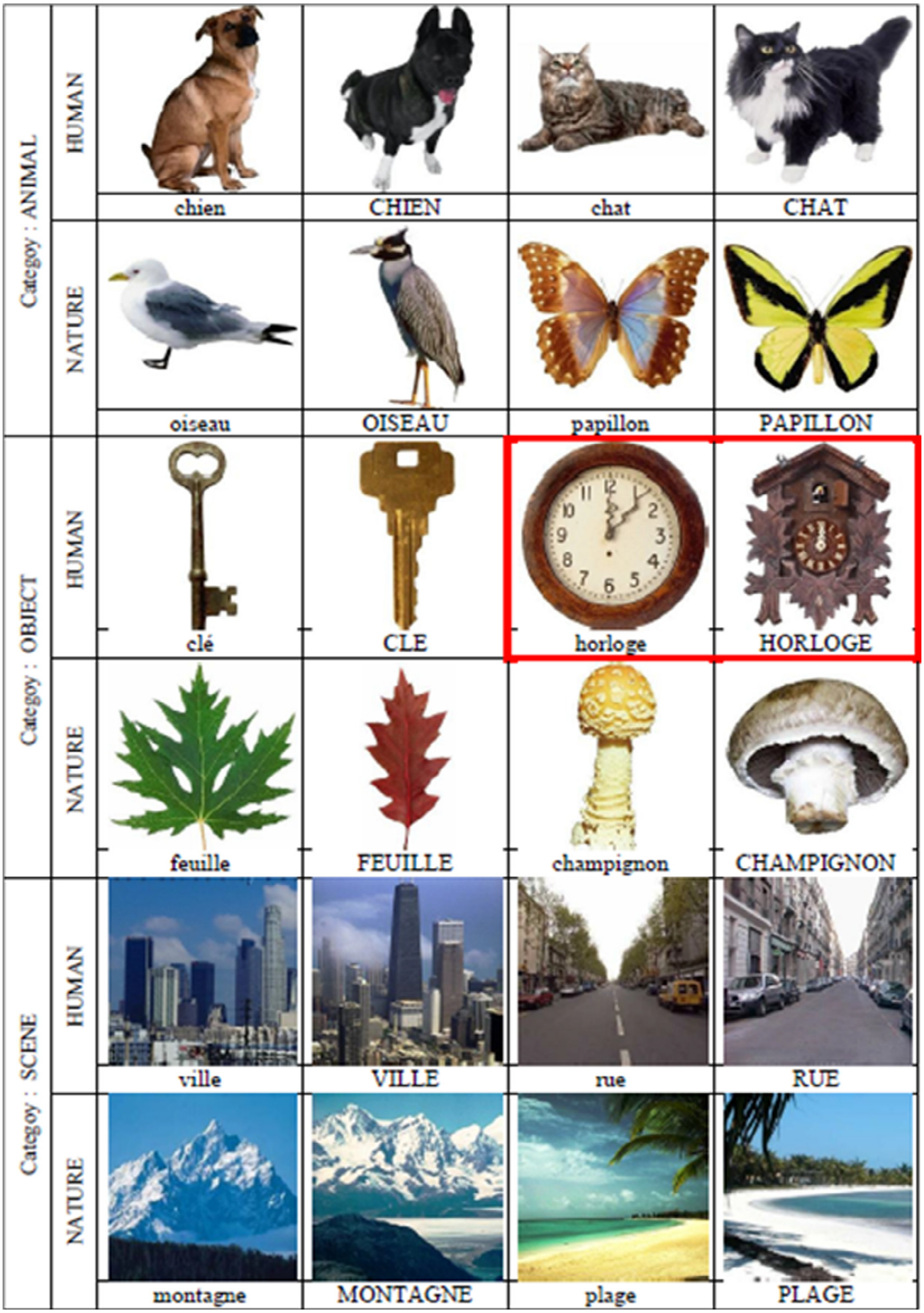
Appendix

Table of the 48 stimuli of Exp. 2. The red frame indicates a set of possible targets (here "clock"). English translations of the French words are: dog, cat, bird, butterfly, key, clock, leaf, mushroom, city, street, mountain, beach.



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