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Eye behavior predicts susceptibility to visual distraction during internally directed cognition

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Abstract

When we engage in internally directed cognition (e.g. planning or imagination), our eye behavior decouples from external stimuli and couples to internal representations (e.g. internal visualizations of ideas). Here, we investigated whether eye behavior predicts the susceptibility to visual distraction during internally directed cognition. To this end, participants performed a divergent thinking task — which required internally directed cognition to generate creative ideas—while being confronted with distractor pictures. We used multi-level mixed models to relate eye parameters right before distractor onset to visual distraction. In Study 1 ($N = 38$), visual distraction was predicted by increased saccade and blink rate, and higher pupil dilation. We replicated these findings in Study 2 using the same task but with less predictable distractor onsets and a larger sample ($N = 144$). The large sample further enabled us to explore how individual differences in the susceptibility to visual distraction relate to cognitive ability and task performance. Taken together, variation in eye behavior was found to be a consistent predictor of visual distraction during internally directed cognition, which highlights the usefulness of eye parameters as indicators of internal vs. external attentional focus and distractibility during complex mental tasks.

Keywords: internally directed cognition, divergent thinking, creativity, eye behavior, visual distraction

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During activities that require predominantly internally directed cognition (IDC) like planning and imagination, attention is focused on the processing of internally generated information, whereas during activities mainly requiring externally directed cognition (EDC) like reading, attention is focused on the processing of sensory information (Andrews-Hanna, Smallwood, & Spreng, 2014; Chun, Golomb, & Turk-Browne, 2011; Dixon, Fox, & Christoff, 2014). Since attentional resources are limited, pursuing extended IDC or EDC activities requires to maintain a sustained attentional focus. However, sometimes we get distracted by irrelevant internal or external information (Smallwood & Schooler, 2015). For example, while reading, we might start thinking about a bothering event (mind wandering). And while planning a lecture, we might get distracted by a notification from our email program (visual distraction). It can be assumed that the level of absorption and distractibility during tasks requiring IDC/EDC varies gradually, for example it may vary with the difficulty of the task at hand. Here, we tested whether eye behavior reflects the variability of absorption during IDC and thus predicts susceptibility to external visual distraction. To test this, participants performed an internal task – idea generation – while being confronted with distracting pictures.

In 1971, Singer, Greenberg, and Antrobus showed that the eyes exhibit particular patterns during internal tasks. They found that daydreaming led to “ocular quiescence,” while active thinking (i.e., visual imagery and suppression of a wish) was associated with considerably more eye movements and blinks. Recent studies investigating typical eye behavior during internal focus extended this research by comparing internal to external tasks and conditions. One study compared divergent thinking and letter-reading, two tasks that differ in their focus of attention (IDC vs. EDC) but do not require eye movements (Walcher, Körner, & Benedek, 2017). IDC was associated with more and longer blinks, and fewer microsaccades, more saccades, higher microsaccade amplitude, and larger pupil diameter than EDC. Another study varied the focus of attention by means of conditional stimulus masking, and found that IDC was again associated with more blinks and larger pupil diameter, but fewer saccades compared to EDC (Benedek, Stoiser, Walcher, & Körner, 2017).

Taken together, internal and external tasks are characterized by different eye behavior. Differences in eye behavior between IDC and EDC are thought to reflect perceptual decoupling from sensory information (Smallwood & Schooler, 2006). Moreover, during IDC, eye behavior may get coupled to internal processes (Bone et al., 2018; Ferreira, Apel, & Henderson, 2008; Johansson & Johansson, 2013) and characteristics of imagined stimuli (e.g. luminance, size, distance; Brandt & Stark, 1997; Laeng & Sulutvedt, 2014; Sulutvedt, Mannix, & Laeng, 2018). The specific differences between IDC and EDC depend on actual characteristics of IDC and EDC activities: When the external task or condition requires constant eye movements (e.g. reading), eye activity during EDC is typically higher than during IDC (Benedek, Stoiser, et al., 2017). In contrast, when the external task requires focusing on a fixed target, eye activity during IDC is typically higher (Annerer-Walcher, Körner, & Benedek, 2018; Franklin, Broadway, Mrazek, Smallwood, & Schooler, 2013; Walcher et al., 2017).

In the present study, participants performed an idea generation task. Such a task elicits a pattern of larger pupil diameter, more blinks, and more saccades (Singer et al., 1971; Walcher et al., 2017) when compared directly to an external task. However, it is unclear how variability of the internal focus and thus the susceptibility to external visual distraction *during* this internal task is reflected in eye behavior. To our knowledge, there exists no study that has investigated eye behavior predicting visual distraction during an internal task. However, mind wandering research could give a hint at possible eye behavior patterns. In mind wandering studies, one is interested in predicting mind wandering episodes (i.e. internal distraction)

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during an external task like reading. Although focus of task and distraction are inverted, both external distraction during an internal task and mind wandering during an external task could reflect failed maintenance of task focus. In mind wandering studies, those episodes of reduced task focus are associated with larger pupil diameter, more blinks, and longer fixations (Franklin, Broadway, et al., 2013; Konishi, Brown, Battaglini, & Smallwood, 2017; Reichle, Reineberg, & Schooler, 2010; Smallwood et al., 2011; Smilek, Carriere, & Cheyne, 2010; Unsworth & Robison, 2018). It is possible that such a pattern also emerges for external visual distraction during an internal task.

Present study

Maintaining sustained attention for task-related information while ignoring distraction is cognitively demanding, especially over longer periods. Depending on task characteristics and cognitive resources, attentional focus may vary from deep absorption to considerable susceptibility for distraction. Since internally and externally directed attention differ in eye behavior, we explored the question of whether eye behavior also predicts variability in the susceptibility to visual distraction during an internal task. In a previous study, we found that during short, highly demanding IDC (i.e., mental arithmetic) attentional focus was very high, as indicated by very low susceptibility to visual distraction (Annerer-Walcher et al., 2018). In the present work, we examined longer-lasting IDC, which is expected to exhibit higher variability in task focus and thus in susceptibility to distraction. Specifically, we had participants work on a creative idea generation task while continuously probing their current susceptibility to visual distraction with the presentation of irrelevant distractor pictures. We investigated whether eye behavior right before distractor onset predicts the likelihood of visual distraction and thus represents a graded index of attentional focus. We considered four eye parameters (pupil diameter, fixation disparity, blink rate, and saccade rate) that were sensitive to attentional focus in previous studies. It is still unclear how susceptibility to visual distraction within the idea generation task is reflected in eye behavior. If high susceptibility to visual distraction represents a shift from internal to external attentional focus, we would expect that visual distraction can be predicted by an eye behavior pattern more compatible with EDC: smaller pupil diameter, smaller fixation disparity, fewer blinks, and fewer saccades (Benedek, Stoiser, et al., 2017; Salvi, Bricolo, Franconeri, Kounios, & Beeman, 2015; Walcher et al., 2017). In contrast, if high susceptibility to visual distraction reflects reduced task focus (e.g., due to executive failure in maintaining internal attentional focus), we would expect that visual distraction is predicted by an eye behavior pattern that is more typical for mind wandering: larger pupil diameter, more blinks, and more saccades (Franklin, Broadway, et al., 2013; Konishi et al., 2017; Reichle et al., 2010; Smallwood et al., 2011; Smilek et al., 2010; Unsworth & Robison, 2018).

Study 1**Method**

We provide our materials, data, and analysis scripts on the Open Science Framework (OSF, link: <https://osf.io/j8kdp/>, DOI: 10.17605/OSF.IO/J8KDP).

Participants

Thirty-eight adults (26 female) aged 19 to 47 years ($M = 25.74$, $SD = 6.07$) participated in Study 1 for payment (€ 10/h). Most participants were students of local universities (84%). Twenty-five participants had normal vision and thirteen participants had corrected-to-normal vision (soft contact lenses) and reported no strabismus or other medical conditions affecting vision. Three additional participants were excluded from further analyses, because of excessive missing data (> 50%) due to eye tracker malfunction.

All participants gave written informed consent. The study procedure was approved by the local ethics committee.

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Sample size was determined a priori based on previous studies examining eye behavior during IDC and EDC (Annerer-Walcher et al., 2018; Benedek, Stoiser, et al., 2017; Smallwood et al., 2011; Unsworth & Robison, 2016) and suggestions for generalized linear mixed effect models (Brysbaert & Stevens, 2018).

With the final sample of 38 participants and 80 pictures per participant, a total of 2,219 usable observations were collected. Simulations using the *powerSim* function of the *simr*-package (Green & MacLeod, 2016) calculated a power of 43.21 to 71.81 percent to detect an effect of .40 for pupil diameter.

Apparatus

The study took place in a sound-attenuated room with lights on. Participants were seated in front of a 24-inch screen (1920 x 1080 pixels, ca. 43.0 x 24.2 degrees of visual angle, 60 Hz refresh rate) at a distance of 70 cm, and their heads were stabilized by a chin rest.

Binocular eye data were recorded using an SMI RED250mobile system (SensoMotoric Instruments, Germany) with a temporal resolution of 250 Hz. The stimulus presentation program was written in PsychoPy (Peirce, 2007) using the Software Development Kit by SMI. There was a 9-point calibration procedure at the beginning of the practice and main block and a drift check before each task.

Procedure and task

Participants performed the alternate uses task, a divergent thinking task that is largely independent of sensory processing and therefore represents internally directed cognition (Benedek, 2018; Benedek, Schickel, Jauk, Fink, & Neubauer, 2014). With a relatively long duration of 2 min, this task was expected to ensure variation in the degree of internal focus over time and thus allow for a variation in susceptibility to external stimuli.

Figure 1 illustrates the sequence of events in a trial. At the beginning, participants received an object cue. They had been instructed to find creative new uses for common household objects (see Figure 1A). After a drift check and a 2 s fixation period (fixation cross of 30 pixels, ca. 0.67 degrees of visual angle in height in center of screen), the name of one of six common household objects (aluminum foil, paper clip, rubber band, toilet paper, paper cup, plastic bottle; practice trial: credit card) appeared on the screen for 2 seconds. Then participants had 120 s time to think of creative uses without verbalizing them. During this period a fixation cross was in the center of the screen and ten irrelevant pictures (i.e., distractors, see “Stimulus presentation”) appeared every 12 s for 2 s each (see Figure 1B). Via written instruction, we informed participants that the pictures were irrelevant and that they should maintain gaze on the screen throughout the experiment because eyes were only tracked within the area of the screen. This approach to use attentional capture by distractor images during IDC as index of attentional focus was previously employed by Buetti and Lleras (2016). At the end of each trial, participants were prompted to type in their best and second-best idea. Finally, participants had to indicate how well they were able to ignore the pictures during the task on an 8-point scale ranging from 0 = “not at all” to 7 = “very well”. For better understanding of the following results, we recoded this variable to reflect self-reported distractor interference ranging from 0 = “no interference” to 7 = “strong interference”.

Participants performed one practice trial followed by six experimental trials. In two additional baseline trials which were randomly intermixed with the experimental trials, participants remembered the object’s name only and type it in at the end of the trial. Those trials served as control for general effects of the trial procedure on eye behavior.

Figure 1. (A) Sequence of events in a trial of Study 1 and 2, and (B) time course of distractor presentation during the performance period of Study 1 and 2.

After participants completed all trials, they answered questions regarding their perceived performance, distractor interference (i.e., difficulty to ignore distractors), and affective state during the trials (see Table S1 in the Appendix). The study took about 45 min. It was part of a larger test session that included other paradigms and questionnaires which were not related to the present study. The total test session took 2.5 h.

Stimulus presentation

The screen background was gray (RGB 128,128,128) and all text and fixation stimuli were white. As distractors, we selected 80 color pictures from the International Affective Picture Scale (Lang, Bradley, & Cuthbert, 2008; picture numbers are listed in the Supplemental material). We selected pictures that were neutral in valence ($M = 5.22$, $SD = 0.42$, range: 4.21 – 6.09) and low in arousal ($M = 3.53$, $SD = 0.40$, range: 2.77 – 4.23) and 50 % contained a human face. We scaled all pictures to 469 x 345 pixels (ca. 10.5 x 7.7 degrees of visual angle). To reduce effects of brightness and contrast, we unified perceived brightness (mean $(0.299 \cdot R + 0.587 \cdot G + 0.114 \cdot B) = 0.5$; Ridpath & Chisholm, 2000) and RMS contrast (Root mean square contrast of 0.5) of all pictures.

For each trial, ten distractors were selected quasi randomly (each picture could appear once in the entire experiment). The first distractor appeared 10s after offset of the object cue. Then, every twelve seconds a picture appeared for two seconds at one of four positions: top left, top right, bottom right and bottom left. The center of the picture was 345 pixels (ca. 7.7 degrees of visual angle) left or right and 270 pixels (ca. 6.0 degrees of visual angle) above or below the center of the screen. A picture never appeared at the position of the preceding one. A trial ended with the two-second presentation of the last picture. During the whole trial, a fixation cross was presented in the center of the screen (height: 30 pixels, ca. 0.67 degrees of visual angle).

Data preprocessing

From raw pupil and gaze position data, we excluded samples recorded during a blink plus 2 (=8ms) additional samples at the beginning and the end of a blink to remove distorted data due to lid closure (percent data discarded: $M = 10.79$, $SD = 6.49$, $Max = 27.06$). We also excluded samples in which pupil diameter (PD) or fixation disparity (FD) were beyond their natural range ($PD > 15$ mm or $PD < 1.8$ mm, $|FD| > \text{mean pupil distance} = 60$ mm) or three standard deviations beyond an individual's mean (percent data discarded: $M = 1.99$, $SD = 1.56$, $Max = 7.09$) to avoid data distortion due to measurement errors.

Saccades and microsaccades were determined using the Microsaccade Toolbox for R (Engbert, Sinn, Mergenthaler, & Trukenbrod, 2015) with $\lambda = 6$ for velocity threshold and a minimum duration of 8 ms (two samples). We considered only binocular saccades with a minimum overlap of one sample. We classified saccades smaller or equal 1.5° as microsaccades (Martinez-Conde, Macknik, Troncoso, & Hubel, 2009).

Pupil diameter and fixation disparity data were analyzed for time periods that were not a blink, saccade, or microsaccade. For each trial, pupil diameter and fixation disparity were z-transformed based on the 2 s fixation period at the beginning of that trial.

We divided each trial into ten segments representing 2-s periods preceding the ten distractor onsets. We used these relatively long time segments because saccades, microsaccades, and blinks are too rare for shorter time windows. We summed onsets of saccades, microsaccades, and blinks, and calculated medians of pupil diameter and fixation disparity for each segment. Saccades and microsaccades were still too rare (many segments with 0), so we collapsed saccades and microsaccades into a general saccade variable (Otero-Millan, Troncoso, Macknik, Serrano-Pedraza, & Martinez-Conde, 2016). We determined visual distraction by assessing whether participants looked at a picture (i.e., gaze on picture region) or not.

Task performance was scored with respect to the rated creativity of the generated ideas. Four experienced raters rated the creativity of all ideas ($\alpha = .68$) on a four-point scale ranging from 0 = *not creative* to 3 = *very creative* (Benedek, Mühlmann, Jauk, & Neubauer, 2013). Ratings were averaged across raters to yield a creativity score for each trial.

Data analysis

We used generalized linear mixed effects models because this method can be applied to a trial-level dataset without the information loss that results from aggregating observations. This approach models both fixed and random effects, which offer more power and can handle unbalanced designs and missing data (Brysbaert & Stevens, 2018). We calculated generalized linear mixed-effects models using the *lme4* package (Bates, Machler, Bolker, & Walker, 2015) for R (R Core Team, 2016) and compared models using the *car* package (Fox & Weisberg, 2011). To assess significance of fixed effects, we applied the Satterthwaite approximation from the *lmerTest* package (Kuznetsova, Brockhoff, & Christensen, 2017).

To assess if eye behavior 2s prior to distractor onset predicts visual distraction (no/yes) we entered pupil diameter, fixation disparity, blink rate, and saccade rate as fixed effects. We added time of picture within trial (picture position) and time of trial within the experiment (trial position) as additional fixed effects to control for time-on-task effects. Regarding the random structure of our model, we included random intercepts for participants and pictures. We did not include random slopes because the model failed to converge.

Results and Discussion

Task performance

Participants were able to name two ideas in all trials, except for one participant who was not able to produce a second idea in one trial. Mean originality of the two ideas was 1.14 ($SD = 0.32$, range: 0.06 – 1.75). 34.52 % ($SD = 30.44$) of distractor pictures were able to

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capture attention, which suggests substantial variation in attentional focus despite successful idea generation.

Eye behavior

Table 1 presents descriptive statistics of eye parameters separately for visual distraction (no/yes) and Table S2 shows bivariate correlations between variables of the model. The generalized linear mixed-effects model analysis revealed significant fixed effects for pupil diameter, blink rate, saccade rate, trial position, and picture position (see Table 2 and Figure 2). Fixation disparity did not contribute significantly to the prediction of visual distraction. Visual distraction was predicted by higher blink rate and saccade rate and stronger pupil dilation right before distractor onset. These results suggest that pupil, blinks, and saccade activity indicate transient variations in the susceptibility to visual distraction during IDC. There were also time effects. The probability to look at distractors increased from the first to the last trial, and from the first picture to the last picture within trials. These effects might reflect general decreases over time in cognitive resources needed to focus on the internal task and to ignore distractors.

In the baseline trials, visual distraction was predicted by stronger pupil dilation and smaller fixation disparity. Blink rate and saccade rate did not contribute to the model in baseline trials (see Tables S3 to S5 in the Supplemental materials) suggesting that they are specific for more goal-directed IDC.

Table 1

Descriptive statistics of average eye behavior 2s before distractor onset depending on visual distraction (no/yes).

Variable	Study 1				Study 2			
	Visual distraction				Visual distraction			
	No		Yes		No		Yes	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Pupil diameter	4.19	0.17	4.25	0.24	4.50	0.10	4.52	0.10
Fixation disparity	0.30	2.46	-0.01	3.00	1.59	2.25	1.05	2.25
Blink rate	0.40	0.13	0.46	0.13	0.34	0.11	0.40	0.11
Saccade rate	0.36	0.17	0.55	0.20	0.37	0.18	0.49	0.18

Note.

Table 2

Generalized linear mixed-effects models predicting visual distraction in Study 1 and Study 2.

	<i>b</i>	<i>SE</i>	<i>z</i>	<i>p</i>	95% CI
Study 1					
(N = 38, observations = 2219)					
(Intercept)	-2.05	0.38	-5.32	<.001	-2.80, -1.29
Pupil diameter	0.60	0.20	3.01	.003	0.21, 1.00
Fixation disparity	0.01	0.01	1.02	.309	-0.01, 0.04
Blink rate	0.40	0.16	2.46	.014	0.08, 0.71
Saccade rate	0.52	0.10	5.21	<.001	0.32, 0.71
Trial position	0.09	0.03	3.46	.001	0.04, 0.14
Picture position	0.06	0.02	2.93	.003	0.02, 0.10
R ² m = 5%					

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$R^2c = 57\%$
 $\chi^2 = 61.05, df = 6, p < .001$

Study 2

($N = 144$, observations = 10209)

(Intercept)	-1.48	0.19	-7.90	<.001	-1.85, -1.11
Pupil diameter	0.38	0.09	4.31	<.001	0.21, 0.55
Fixation disparity	-0.01	0.01	-2.78	.005*	-0.02, -0.01
Blink rate	0.45	0.07	5.98	<.001	0.30, 0.59
Saccade rate	0.38	0.04	8.93	<.001	0.30, 0.47
Trial position	0.05	0.01	3.95	<.001	0.02, 0.07
Picture position	0.06	0.02	3.22	.001	0.02, 0.10

$R^2m = 3\%$
 $R^2c = 48\%$
 $\chi^2 = 162.17, df = 6, p < .001$

Note. 95% CI = 95% confidence intervals. R^2m denotes variance explained by the fixed effects and R^2c denotes variance explained by fixed and random effects.
* Fixation disparity was significant in the model, however removing fixation disparity did not harm model fit significantly.

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Figure 2. Illustration of the generalized linear mixed-effects model predicting visual distraction in Study 1. (A) Fixed effects, (B) random intercepts. Pupil diameter (mm) is centered to zero.

Regarding random effects, random intercepts for pictures were not significant (variance = 0.02, $SD = 0.15$, $\chi^2 = 0.24$, $p = .621$) suggesting that the specific characteristics of distractor pictures (e.g. faces vs. no faces, color) had no significant influence on whether they caught attention or not. There was a large effect of random intercepts for participants (variance = 3.97, $SD = 1.99$, $\chi^2 = 798.13$, $p < .001$, see Figure 2). Participants varied strongly in their distraction rate, suggesting considerable individual difference in the capacity to maintain sustained internally directed attention despite distraction (see supplemental materials).

To further explore the effect of visual distraction on task performance, we examined relationships between distraction rate, self-reported distractor interference, and response originality. Relations were analyzed at the within-subject level (across trials) and at the between-subject level (across participants). Self-reported distractor interference tended to be higher for trials with higher distraction rates ($M = .34$, $SD = .40$, range: $-.81$ to $.92$), but there was no significant relationship at the between-subjects level ($r = .18$, $p = .285$). Interestingly, distraction rate and self-reported distractor interference was not related to response originality, neither at the within-subject level ($M = .07$, $SD = .39$, range: $-.48$ – $.84$; $M = -.06$, $SD = .42$, range: $-.82$ to $.72$) nor at the between-subject level ($r = -.04$, $p = .814$; $r = -.11$, $p = .521$).

In sum, the extended IDC task allowed considerable rates of visual distraction (36%), and higher susceptibility to visual distraction was predicted by higher pupil diameter, blink rate, and saccade rate. Interestingly, distraction rates were only weakly related to self-reported distraction interference and were not systematically associated with task performance.

As a limitation of this study, distractor pictures appeared at a fixed interval of 12 s, which makes them predictable and thus less distracting. From research on mind wandering, we know that people can adapt their mind wandering to task demands (Seli et al., 2018). Moreover, Unsworth, Robison and Miller (2018) found that pupil diameter increases when expecting a relevant stimulus, a result to which the authors refer as *increase in intrinsic alertness*. In their study, this preparatory increase of pupil diameter was somewhat smaller for longer ISIs (8s compared to 2s). Even in trials with the slowest responses, pupil diameter increased in anticipation of the next stimulus (although not as much as in trials with the fastest responses; Unsworth et al., 2018). As distractor onsets were fixed in Study 1, differences in eye parameters could be the result of successful prediction of distractor onsets. Therefore, in Study 2, we tested whether our findings are robust against less predictable picture onsets. Specifically, we varied the time between distractors (4 – 6s) and the number of distractors per trial (7 – 11), as well as total trial duration (50 – 70s). Furthermore, we increased sample size in Study 2 to increase statistical power of within- and between-subject effect analyses.

Study 2

Method

We provide our materials, data, and analysis scripts on the Open Science Framework (OSF, link: <https://osf.io/j8kdp/>, DOI: 10.17605/OSF.IO/J8KDP).

Participants

The final sample consisted of 144 adults (105 female) aged 19 to 48 years ($M = 24.33$, $SD = 4.76$). They participated for payment (€ 10/h). Most participants were students (88.2 %). One hundred and twenty-eight participants had normal vision; sixteen participants had

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corrected-to-normal vision (soft contact lenses) and reported no strabismus or other medical conditions affecting vision. All participants gave written informed consent.

We excluded thirteen additional participants from analyses (9 female; mean age = 24.38). Five had excessive missing data (> 50%) due to eye tracker malfunction. Eight participants were able to ignore all pictures, leaving no variance in susceptibility to visual distraction to analyze.

With the final sample of 144 participants and 72 pictures per participant, a total of 10,209 usable observations were collected. Simulations using the *powerSim* function of the *simr*-package (Green & MacLeod, 2016) calculated a power of 92.89 to 100 percent to detect an effect of .40 for pupil diameter.

Procedure, task and apparatus

The same eye tracker was used as in Study 1.

The paradigm of Study 2 was identical to Study 1 (see Figure 1) except for a few small changes mainly targeted to increase the unpredictability of distractor onsets and to increase the power of analyses: (1) Participants performed eight experimental trials instead of six. (2) We reduced trial durations from 120 s to a varying duration of 50 to 70 s. Within trials, (3) 8 to 12 pictures were presented instead of 10 (4) for 1 s instead of 2 s, and (5) with a reduced and varying inter-stimulus interval between distractors (4, 4.5, 5, 5.5, 6s) instead of a fixed interval of 10s. Pictures were quasi-randomly selected from the 80 pictures of Study 1 and inter-trial-intervals were randomized. We excluded the last picture of each trial from analysis, because data acquisition ended during picture presentation, cutting short the time in which looking at a picture would have been possible. In total, 72 picture presentations per participant were considered in the analyses.

Study 2 was part of a larger test session. The first part was a 45 minute online session (at home using LimeSurvey, LimeSurvey Project Team/ Carsten Schmitz, 2015) including questionnaires on personality traits, mind wandering and psychological health. The second part was a 3.5 hour session in our lab with breaks. In the lab session, participants performed cognitive tests (see supplemental material), the present paradigm and two further eye-tracking experiments, not related to the present manuscript.

Data preprocessing and analysis

Data preprocessing and analysis was identical to Study 1. On average, 12.40 % of samples were excluded due to blinks ($SD = 9.14$, Max = 42.06) and 3.18% due to pupil diameter and fixation disparity outliers ($SD = 2.38$, Max = 10.71). The number of valid segments per participant ranged from 68 to 72. The originality of generated ideas were rated by eight experienced raters to ensure good inter-rater reliability ($\alpha = .74$).

Results and Discussion**Task performance**

Participants were able to name a best idea in all trials and a second best idea in 96% of trials. Mean originality of the two ideas was rated 1.03 ($SD = 0.21$, range: 0.49 – 1.82). On average participants looked at 28.31 out of 72 distractor pictures ($SD = 20.52$, range: 1 – 71), which corresponded to an average distraction rate of 39.37% (only segments with available eye data were considered), similar to Study 1.

Eye behavior

Table 1 presents descriptive statistics of eye parameters separately for visual distraction (no/yes) and Table S2 shows bivariate correlations between variables of the model across samples.

We used the same model in the generalized linear mixed-effects analysis as in Study 1. The final model revealed significant fixed effects for pupil diameter, blink rate, saccade rate, trial position, and picture position (see Table 2 and Figure 3), while fixation disparity did not contribute to the model. As in Study 1, the probability of visual distraction increased

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with higher pupil diameter, saccade rate, and blink rate. Moreover, similar to Study 1, visual distraction further increased with time within and across trials. Thus, the pattern of fixed effects was identical to Study 1 (see Table 2). This underlines the robustness of eye parameters as predictors of visual distractibility despite reduced predictability of picture onsets.

Figure 3. Illustration of the generalized linear mixed-effects model predicting visual distraction in Study 2. (A) Fixed effects, (B) random intercepts. Pupil diameter is centered.

Random intercepts for pictures were significant (variance = 0.14, $SD = 0.38$, $\chi^2 = 113.17$, $p < .001$) suggesting that characteristics of distractor pictures (e.g. faces vs. no faces, color) had some influence on whether they were looked at or not (see Figure 3B). There was again a large effect of random intercepts for participants (variance = 2.68, $SD = 1.64$, $\chi^2 = 2901.68$, $p < .001$, see Figure 3B). Participants varied strongly in their distraction rate. We tested the idea that individual differences in susceptibility to visual distraction may be related to cognitive abilities. Exploratory analysis showed that attention capacity, executive functioning, creative potential, and openness measures only marginally predicted the distraction rate in the divergent thinking task (see supplemental material).

We found the same (lack of) correlations between distraction rate, self-reported distractor interference, and task performance (originality of ideas) at the within-subject and between-subject level as in Study 1. Self-reported distractor interference tended to be higher in trials with higher distraction rate ($M = .27$, $SD = .40$, range: $-.66$ to $.97$) and for participants with higher distraction rate ($r = .15$, $p = .064$). Yet, distraction rates and self-reported distractor interference did not predict task performance, neither at the within-subject level (M

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= .00, $SD = .37$, range: $-.90 - .86$ and $M = .08$, $SD = .35$, range: $-.79 - .85$, see Figure 4A) nor the between-subject level ($r = -.01$, $p = .936$ and $r = -.11$, $p = .198$, see Figure 4B).

These results provide further support that susceptibility to visual distraction during idea generation had no overall effects on idea generation performance. The broad range of within-subject correlations between distraction rate and originality suggests that some participants' performance suffered from visual distraction whereas others' performance was unaffected or may have even benefitted (see Figure 4A). Similarly, investigations of the relationship between mind wandering and creativity have revealed mixed findings. Mind wandering (spontaneous task-unrelated internal attention focus) during idea generation was found to be detrimental for task performance (Hao, Wu, Runco, & Pina, 2015), but has no effect when it occurs during incubation periods (Smeekens & Kane, 2016); yet, trait mind wandering propensity was shown to be positively related to creative task performance (Agnoli, Vanucci, Pelagatti, & Corazza, 2018). To closer investigate potentially different effects of spontaneous external and internal attention focus (mind wandering) on idea generation performance, future studies should assess both simultaneously.

Figure 4. Within-subject (A) and between-subject (B) analyses: Correlations between distraction rates (% distraction), self-reported distractor interference (self-rated interference) and task performance (originality of ideas) in Study 2. Further individual differences analyses are presented in the supplemental materials.

General Discussion

This study investigated eye behavior as indicator of within-task susceptibility to visual distraction during internally directed cognition. Extended task performance of creative idea generation implied substantial rates of visual distraction (35 % and 39%, for Study 1 and 2, respectively), which enabled a powerful analysis of eye behavior predicting whether attention got caught by distractors or not. Visual distraction was preceded by more blinks,

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more saccades, as well as higher pupil dilation. Results replicated across two studies with different predictability of distractor onsets, underlining the robustness of the findings.

The present findings are strikingly similar to those observed during mind wandering episodes. In mind wandering studies, (internal) distraction within an external task is also preceded by larger pupil diameter, more blinks, and more saccades (Franklin, Mrazek, Broadway, & Schooler, 2013; Konishi et al., 2017; Reichle et al., 2010; Smallwood et al., 2011; Smilek et al., 2010; Unsworth & Robison, 2018). Although attentional focus of distraction and task are inversed, both mind wandering studies and the present paradigm share failures in maintaining task focus in face of (internal or external) distraction. The consistent eye behavior pattern observed during mind wandering and visual distraction may hence reflect incidents of failed or reduced task focus during extended task engagement.

While reduced task focus typically leads to impaired task performance in mind wandering studies, no impairments were observed in the present study. This may be explained by the fact that mind wandering studies assess performance more sensitively (e.g. response time per trial; Smallwood et al., 2011). Moreover, distraction and reduced control are discussed to have negative as well as positive effects on creative performance (e.g., Baird et al., 2012). This may explain why we observed no correlation between distraction rates and creative task performance.

Like mind wandering episodes, visual distraction during an internal task was preceded by larger pupil diameter and more blinks. Increases in pupil diameter are also known to reflect increases in cognitive load (Kahneman & Beatty, 1966; Piquado, Isaacowitz, & Wingfield, 2010). Maintaining sustained internally directed attention in face of distraction may become increasingly cognitively taxing as evidenced by increases in distraction rates over time. In moments of excessive cognitive demands (as indicated by large pupil diameter and potentially high compensatory blink rate), people may sometimes fail to maintain the internal focus of attention and get distracted by salient sensory stimulation, thereby interrupting the internal stream of thought. Further studies assessing both visual distraction and mind wandering during an internal task should explore whether visual distraction and mind wandering can actually be discriminated at the level of eye behavior.

The heightened saccadic activity right before visual distraction could mark reduced coupling to imagination processes and increased spontaneous sampling of visual information (even when no relevant information is available yet). Similarly, searching for visual information in the external environment is associated with more saccades than focusing on something (Ehrlichman & Micic, 2012). In a state of increased spontaneous sampling of visual information it can be assumed that people are more likely to notice and attend to visual distractors.

The current results oppose the notion that susceptibility to visual distraction is simply akin to a more external focus. Several studies have reported more or longer blinks and larger pupil diameter during IDC compared to EDC (Annerer-Walcher et al., 2018; Benedek, Stoiser, et al., 2017; Salvi et al., 2015; Savage, Potter, & Tatler, 2013; Smilek et al., 2010; Walcher et al., 2017) and have argued that blink rate is reduced in states of heightened focus to sensory information (Shin et al., 2015; Shultz, Klin, & Jones, 2011), whereas higher blink rate may facilitate the shielding of an internal train of thought by direct attenuation of visual input (Benedek, Stoiser, et al., 2017; Salvi et al., 2015; Walcher et al., 2017). Moreover, larger pupil diameter is commonly viewed as an indicator of increased mental load (Kahneman & Beatty, 1966; Piquado et al., 2010), and goal-directed IDC often involves high workload as all relevant information must be kept in working memory and cannot be externally retrieved (Benedek, Bergner, Könen, Fink, & Neubauer, 2011; Benedek et al., 2014). Notably, studies comparing internal and external tasks differ fundamentally from the present design. In the former, goal-directed IDC is compared to goal-directed EDC and

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distraction during the internal task is typically minimal (Benedek, Stoiser, et al., 2017; Walcher et al., 2017). Here, we studied how variation in the susceptibility to visual distraction *during* an internal task is reflected in eye behavior. And the present findings showed that eye behavior differences between low and high susceptibility to visual distraction within an internal task are not consistent with eye behavior differences between goal-directed IDC and goal-directed EDC.

In the present study, distraction rates varied considerably across participants. Moreover, we also observed large individual differences in the relationship between distraction rate and creative task performance (range: -.90 to .86). These findings suggest that visual distraction could be both beneficial for some people and for others detrimental for the idea generation process. It is assumed that both spontaneous and controlled processes are relevant to creative cognition (Beaty, Silvia, Nusbaum, Jauk, & Benedek, 2014; for reviews, see Benedek & Jauk, 2018; Chrysikou, 2018). On the one hand, there is robust evidence that higher executive capacity predicts higher creative task performance (Benedek, Jauk, Sommer, Arendasy, & Neubauer, 2014; Silvia, 2015), but on the other hand, creativity is sometimes found to benefit from states of reduced control (e.g., Benedek, Panzierer, Jauk, & Neubauer, 2017; Gable, Hopper, & Schooler, 2019; Radel, Davranche, Fournier, & Dietrich, 2015). This may be related to the ambiguous role of task-irrelevant information for creative thought: Looking at distractor pictures could have triggered spontaneous autobiographical or semantic memories (Faber & D'Mello, 2018), which may sometimes have promoted performance by inspiring novel associations for possible uses and sometimes may have hampered performance by simply interrupting the ongoing internal train of thought.

The present study showed that it is difficult to maintain an internal attention focus for 1-2 minutes as visual distractors frequently catch our attention. Visual distraction was predicted by pupil dilation, and increased blink and saccade rate. These results favor a reduced/failed task focus interpretation over an external attention interpretation to explain variation in the susceptibility to visual distraction. Moreover, the findings highlight that eye behavior represents a sensitive indicator of attentional focus within complex mental tasks.

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Supplemental Material

To the manuscript

Eye behavior predicts susceptibility to visual distraction during internally directed cognition

By Sonja Annerer-Walcher, Christof Körner, Roger Beaty and Mathias Benedek

List of images

Image numbers:

Main tasks ($N = 80$): 1670, 2002, 2020, 2038, 2101, 2102, 2214, 2215, 2235, 2305, 2308, 2357, 2372, 2382, 2390, 2393, 2397, 2400, 2411, 2489, 2512, 2513, 2514, 2575, 2579, 2593, 2594, 2597, 2690, 2749, 2850, 2890, 4500, 4510, 4573, 5120, 5250, 5395, 5471, 5520, 5531, 5532, 5534, 5535, 7002, 7003, 7019, 7030, 7032, 7036, 7038, 7042, 7043, 7052, 7057, 7081, 7096, 7161, 7165, 7192, 7205, 7207, 7211, 7242, 7290, 7300, 7354, 7365, 7487, 7493, 7495, 7546, 7547, 7595, 7710, 8121, 8312, 8465, 9210, 9401.

Practice task ($N = 10$): 2221, 2383, 2506, 4274, 5510, 5530, 7050, 7179, 7233, 9260.

Valence: $M = 5.22$, range: 4.21 – 6.09.

Arousal: $M = 3.53$, range: 2.77 – 4.23.

Table S1

Descriptive statistics of questions asked after end of Study 1.

Question	Scale	M	SD
During idea generation, I was distracted by thoughts, daydreams and/or feelings. Internal information sources	1 = never 6 = very often	3.00	1.34
During idea generation, I was distracted by external stimuli (e.g. sounds, flicker, itches). External information sources	1 = never 6 = very often	2.37	1.50
It was important for me to show good performance.	1 = agree 6 = disagree	4.00	1.19
The idea generation task was fun.	1 = agree 6 = disagree	4.00	1.19
The idea generation task was demanding.	1 = not at all 6 = very	3.13	1.38
Right now, I feel ...	1 = very tired 6 = very awake	3.24	1.34
The pictures were distracting.	1 = agree 6 = disagree	2.87	1.32
Ignoring the pictures was easy for me.	1 = agree 6 = disagree	4.00	1.32
How often did you look at pictures?	1 = never 6 = always	3.26	1.16
The pictures made idea generation task...	1 = harder 6 = easier	3.11	0.83
How often did the pictures help you find new ideas?	1 = never 6 = always	1.76	1.08

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Note. Participants answered those questions after completing all tasks. Due to restricted time, this questionnaire was not presented in Study 2. $N = 38$.

Table S2

Bivariate correlations between variables of the model across samples.

Study 1		1	2	3	4	5	6
1	Visual distraction (0=no, 1=yes)						
2	Pupil diameter	.05					
3	Fixation disparity	.01	.06				
4	Blink rate	.04	.11	.08			
5	Saccade rate	.19	-.03	.00	.14		
6	Trial position	.07	-.07	.02	.04	.04	
7	Picture position	.03	-.16	.00	-.05	-.02	.00

Study 2		1	2	3	4	5	6
1	Visual distraction (0=no, 1=yes)						
2	Pupil diameter	.05					
3	Fixation disparity	.07	-.13				
4	Blink rate	.11	.11	.17			
5	Saccade rate	.21	.05	.01	.02		
6	Trial position	.02	-0.12	.06	.04	.03	
7	Picture position	.04	-0.10	.01	-.07	.00	.01

Note.

Table S3

Study 1, baseline tasks, descriptive statistics of average eye behavior 2s before distractor onset depending on visual distraction (no/yes).

Variable	Visual distraction			
	No		Yes	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Pupil diameter	3.91	0.25	4.04	0.25
Fixation disparity	0.22	3.87	-0.52	2.72
Blink rate	0.31	0.16	0.42	0.18
Saccade rate	0.25	0.20	0.25	0.24

Note.

Table S4

Study 1, baseline tasks, bivariate correlations between variables of the model across all samples.

Variable	1	2	3	4	5	6
1 Visual distraction (0=no, 1=yes)						
2 Pupil diameter	.09					
3 Fixation disparity	.08	.09				

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4	Blink rate	.13	.12	.07		
5	Saccade rate	.18	.08	.02	.25	
6	Trial position	-.04	-.10	.11	-.09	.02
7	Picture position	.07	-.20	-.04	.08	.09
						-.01

Note.

Table S5

General linear mixed models predicting distractor capture in baseline tasks of Study 1.

	<i>b</i>	<i>SE</i>	<i>z</i>	<i>p</i>	95% CI
Baseline tasks (<i>N</i> = 38, samples = 742)					
(Intercept)	-2.41	0.65	-3.71	<.001	-3.48, -1.13
Pupil diameter	1.11	0.38	2.96	.003	0.38, 1.85
Fixation disparity	-0.04	0.03	-1.40	.163	-0.08, 0.01
Blink rate	0.57	0.35	1.65	.099	-0.11, 1.25
Saccade rate	0.00	0.26	0.01	.992	-0.48, 0.49
Trial position	-0.20	0.07	-2.72	.006	-0.35, -0.06
Picture position	0.15	0.05	3.21	.001	0.06, 0.24
<i>R</i> ² _m = 8%					
<i>R</i> ² _c = 71%					
$\chi^2 = 34.02$, <i>df</i> = 6, <i>p</i> < .001					

Note. 95% CI = 95% confidence intervals. *R*²_m denotes variance explained by the fixed effects and *R*²_c denotes variance explained by fixed and random effects.