The Pupillary Light Response Reveals the Content of the Attended Item in Verbal Working Memory

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Abstract

The illustration that verbally comprehending the semantics of an item that convey a sense of brightness or darkness can trigger a pupillary light response offers a novel opportunity to study the focus of attention within verbal working memory. In doing so, the present paper hypothesized while an item that conveys a sense of luminance is at the focus of attention in a verbal working memory task, a pupillary light response should be observable in expected directions. A retro-cue paradigm was employed to isolate attention towards target items (bright vs dark-related), that are known to evoke a pupil light response. The task required the participants to judge whether a verbally cued item, retrieved from a verbal working memory sequence, rhymed or did not rhyme with another matched word. A 3s retention interval after cue onset was the window of interest as the target item should be at the focus of attention during this period. Analysis revealed that while the target items are in a prioritized state (i.e., focus of attention) within verbal working memory a pupillary light response is present. As such, the pupillary light response reveals the content of the attended in verbal working memory. This paper provides further support for previous research on verbal semantic comprehension while also extending similar observations in visual working memory of attention to the verbal domain.

Keywords: pupil light response, attention, verbal working memory, semantics

The Pupillary Light Response Reveals the Content of the Attended Item in Verbal Working Memory

Working memory (WM) is a multicomponent system that supports the capacity for humans to temporarily maintain, store, and manipulate information in mind (Baddeley, 2003; Baddeley & Hitch, 1974). Recent research on working memory has focused on the role of attention to further explore how this cognitive system functions, especially with respect to memory traces (Oberauer, 2002; Cowan, 1995). For instance, orientation of attention to items in working memory can be dynamically changed so as the item of focus can be shifted in or out of a prioritization state (Myers et al., 2017; Griffin & Nobre, 2003; Souza et al., 2018). While an item of focus is prioritised, other items can still be retrieved but they are said to be in separate representational state (Wolff et al., 2017; Cowan, 1995).

Items in the focus of attention within working memory can be expressed via subtle physiological markers. For example, it has been shown that eye movements leftwards and rightwards can reveal the serial position of items at the focus of spatial attention in verbal WM (Sahan et al., 2021). Another indicator of the items at the focus of attention is the pupillary light response (PLR). The PLR is a well-known physiological reflex to brightness or darkness (Mathôt et al., 2018). For example, standing in dark room will cause the pupil to dilate while standing outside on a bright day will induce the pupils to constrict.

A PLR is detectable if an items visual representation includes bright or dark qualities (while in the focus of attention) in visual WM (Hústa et al., 2019; Zokaei et al., 2019). Husta et al., (2019) illustrated such a marker while also distinguishing any effects due to visual WM encoding from visual WM maintenance (unlike Blom et al., 2016). Instead of using an orientation gate (like Zokaei et al., 2019) they simply used a luminance comparison task with a pre-cue and retro-cue. It was shown that visual WM content (bright/dark stimulus) is reflected in the PLR not only during encoding but also during maintenance. Shifting attention within visual WM representations (that are brightness-related) is reflected in pupil size, such that internally shifting attention toward bright stimuli elicits smaller pupils than internally shifting attention toward dark stimuli.

In a similar vein, Zokaei et al., (2019) also examined the top-down modulation of the pupillary response to visual working memory representations of spatial gratings of differential luminance. They did so, unlike the previous study (Hústa et al., 2019), in the absence of any brightness-related confounds that could lead to contaminations by perceptual attention or anticipation. Their task involved the memorization of the orientations of two grates (one dark and one bright) in which an auditory retro-cue would indicate which of the gates was to be attended so as to adjust the probe gate to suit the orientation of the cued gate. Thus, it was hypothesized that a prioritization (i.e., item in focus of attention) of a darker spatial grating during VWM maintenance would elicit a dilation in pupil size compared to prioritizing a bright grating (i.e., a PLR). The authors successfully demonstrated that prioritizing the dark memory item elicited a larger pupil response compared to prioritizing the bright item. Shifting internal visual attention towards a bright or dark stimulus that is maintained in working memory can be reflected in pupil size.

The pupil light response is a useful and dynamic physiological reflex that can reveal complexities of higher-order cognition. While pupils are primarily driven by reflexive adaptation to external stimuli (Mathôt, 2018), the pupil size can be internally modulated by visual awareness and eye movement preparation. Visual awareness of stimuli has been shown to modulate a PLR during interocular suppression (Kimura et al., 2014; Naber et al., 2011).

Typically, this can be induced by dichotically presenting a continuous and abrupt flash of light to one eye (left eye) while showing another image (e.g., spatial grating) to the other (right eye). The eye that is flashed shows a reduced pupil diameter (i.e., a PLR) while the other does not, exemplifying that one has to be visually aware of the stimulus for it to cause such an effect. Eye movement preparation has also been implicated in the modulation of the PLR (Mathôt et al., 2015b). If a saccadic movement is preceded by a covert shift of attention then it is reasonable to assume that the pupil also prepares by dilating or constricting (Deubel & Schneider et al., 1996). Mathôt et al., (2015b) showed that the pupil began to weakly constrict to the brightness of a cued side already while the eyes were already in motion. Showing that the PLR is not a passive response but is prepared alongside movement which makes sense given the tight relationship between attention and eye movements. Findings such as these suggest the PLR is a useful tool in exhibiting of idiosyncrasies in cognition.

It has been shown that the PLR can also be triggered by guiding attention toward internally imagined image that has bright or dark connotations (Laeng & Sulutvedt, 2014; Mathôt et al., 2018). One such study that has exhibited this was executed by Laeng & Sulutvedt (2014) in which they used the logic that a mental image is a re-representation of a perception, presumably retrieved from long-term memory. Following this reasoning and given the imagined image has brightness or darkness properties (e.g., sun or moon), then luminance should also constitute such a mental image and should be observable in the pupil via a PLR. More succinctly, orientating attention towards a bright or dark internal memory representation should trigger a PLR, in expected directions. This assumption proved be true as the pupils of the participants constricted or dilated, respectively, in response to a bright or dark imagined objects and scenarios (e.g., imagine a “sunny sky” or “dark room”).

Pupil size can also reflect the verbal comprehension of words that convey a sense of brightness or darkness. Mathôt et al., (2017) hypothesized that verbally comprehending and, presumably, internally processing the non-linguistic visual information (i.e., creating a sensory representation) of a word that conveys luminance connotations should trigger a PLR in expected directions. Their task used was fairly simple, participants had to listen to words that convey a sense of brightness and darkness while an eye-tracker recorded their pupil diameter. To make sure the subjects actually processed the word meaning they had to press the spacebar when they heard an animal name. On average, hearing and attending to a brightness-related word compared to a darkness-related word resulted in smaller pupil. It should be noted this study utilized French words to achieve this effect but has subsequently been replicated with Dutch words (Mathôt et al., 2019).

While novel, this finding warrants more of an exploration, namely, if this the pupil light response is observable in verbal working memory task when target items are in a prioritized state. Since the pupil can reflect the semantic content of words (Mathôt et al., 2017) and if such a word is at the focus of attention within verbal working memory then the pupil size should reveal semantic category (bright vs dark-related) of the item. As outlined above, the effect has been illustrated using visual representations in visual WM (Zokaei et al., 2019; Hústa et al., 2019). On the other hand, it has not been reported, to our knowledge, in semantic comprehension in verbal WM. Therefore, this offers a novel opportunity to explore this possible phenomenon. In doing so, this paper puts forward two hypotheses:

Hypothesis 1: On average, the pupil will constrict when one attends an item in verbal working memory that conveys a sense of brightness (compared to attending to a word that conveys a sense of darkness)

Hypothesis 2: On average, the pupil will dilate when one attends an item in verbal working memory that conveys s sense of darkness (compared to attending to a word that conveys a sense of brightness)

Methods

Participants

Participants consisted of first year Psychology students from the University of Groningen and were recruited using the SONA system, a cloud-based management system. In total, 35 participants took part in this study, aged from 18 to 29 (M = 20 , SD = 2) (based on Mathôt et al., 2017; 2019). Four participants were excluded from analysis, two on the grounds of corrupted data due to personal errors in setting up the experiment and the other two were a result of malfunctioning equipment. As such, 31 participants were eligible for analysis. Of the included participants, the percentage of females was 87% and the percentage of males was 13%. All subjects had normal or corrected-to-normal vision and gave informed consent. Upon completion of the experiment, the participants received partial course credits. The study was approved by the Ethics Committee of the Faculty of the Behavioural and Social Sciences of the University of Groningen (PSY-2122-S-0182).

Materials and Stimuli

Pupil size of the right eye was recorded using the Eyelink 1000 (SR Research, Mississauga, Canada, ON) while the participants placed their chin on a chin rest at a consistent distance from a monitor. The stimuli were presented on a monitor with an LCD display with a 60 Hz refresh rate and a resolution of 1920 x 1080. Data was sampled at 1000 Hz and collected in a room with controlled lighting to reduce any effect it may have on the pupil. The task was designed in MATLAB using the Psychophysics Toolbox (Brainard, 1997). Stimuli consisted of Dutch words taken from Mathôt et al., (2019) that are known to provoke a PLR. Words were selected via strict criteria that were matched on the number of letters (bright: M = 5.96; dark: M = 5.83; range: 3 - 11) and lexical frequency (how often a word occurs in books) (bright: M = 2,839 occurrences per million; dark: M = 2,781; range = 52 -25,976). Matching for lexical frequency allows for the control of the pupils sensitivity to changes in task difficulty. Additionally, the valence and saliency arousal of the matched words was controlled for, to prevent any effect of arousal-related dilation (Mathôt et al., 2017). In total, there were 77 words used and each pertain to one of four categories: Dark (N = 20), Bright (N = 20), Animal (N= 17) and Filler (N = 20) (Marian et al., 2012) (Appendix A). Each word was rendered into a sound file using the Mac OS text-to-speech synthesizer Manuscript. The filler words and animal names were not matched, therefore, the brightness- and darkness-related words are only considered in the statistical analyses described below.

Procedure and Design

Trials were grouped into blocks with 40 blocks of 8 trials resulting in 320 trials in total. Each block consisted of three phases: 1) encoding the sequence 2) rhyme judgement and 3) recall of word sequence. Before the start of the experiment, a five-point calibration procedure made sure the eye-tracker was appropriately recording the eye. Participants were then given a practice block (eight trials) to familiarize themselves with the task.

At the start of a block, participants were visually confronted with a black dot signifying the start of a block and were required to press the spacebar while directing their gaze towards a black dot at the centre of the screen. If the block commenced, the drift correction of the eyelink was working appropriately. When the block started the black fixation dot turned grey to convey to the participant that a block had started. At all times during the task, participants were instructed to direct their gaze directly at the grey fixation dot. The screen background was a lighter shade of grey to keep visuals equiluminant.

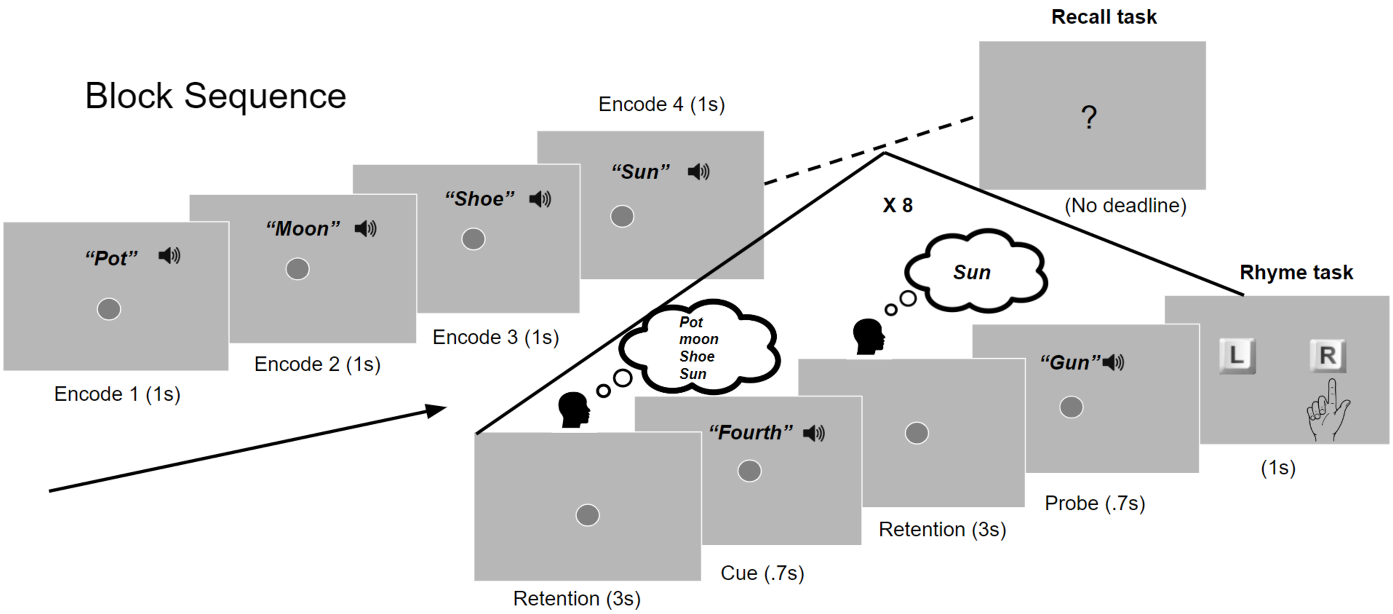
Encoding consisted of the verbal, binaural, and serial presentation of four words at a pace of 1.5s, each pertaining to the four word categories (e.g., sun, pot, moon, shoe). It was important that the participants encode the serial order in which the words as they were presented so they could later complete a phonologically similar/dissimilar comparison. The sequence of words was only heard once per block and eight comparisons were done within one block with each word being compared to their rhyming and non-rhyming counterpart. Of the four words heard, two always conveyed a sense of brightness and darkness, respectively, and every category appeared at each position equally. Following the encoding phase, there was a period of retention that lasted 3 seconds. This period provided the participants a chance to maintain the sequence they just heard in their working memory.

After this retention interval, an auditory retro-cue (.7s) indicated which word in the sequence had to be retrieved. The cue simply stated a number (e.g., "*first*", "*second*", etc.) that pertained to the word in the sequence. For example, if the first word heard was sun and the cue indicated "*fourth*" then participant needed to retrieve the word sun from the sequence. Every sequential position was cued twice and each cue was accompanied by either rhyme or non-rhyming word. After the cue onset, there was another period of retention (3s) in which the subject to allow the subject window to retrieve the word from the memorized sequence. This second retention interval was the window of interest for analysis as target item should be in their verbal WM.

For the rhyme phase a phonologically similar or dissimilar probe was presented. The participant had to judge if this probe rhymed or did not rhyme with the cued word and had to respond as quickly as possible via a corresponding keypress. Responses were counterbalanced for handedness. To simplify instructions in the experiment we referred to the key ‘F’ as the ‘Left key’ and ‘J’ key as the ‘Right key’. The rhyming was controlled for across the whole experiment and not within a block to prevent the rhyming task within a block from becoming predictable. For semantic category, we generated words that rhymed with each word. In the non-rhyming conditions, we randomly sampled words from a list of words that were non-rhyming with any of the words from either semantic category. To extend the example given above, if the cued word was “sun” and the probe was “gun” then the participant had to efficiently press the representative key. If the participant did not press the key within a certain small time interval (1s) then their answers was recorded as a missed opportunity to compare.

For the recall phase, a question mark was presented on screen. When the participants saw this question mark they were required to type, word by word, the sequence of words they heard at the beginning of the block (in the order they heard them). This served to validate if the subjects remembered the words in the correct order or if they heard the words at all. A visualisation of a block can be seen in figure 1, below.

Figure 1



Note: Visual representation of a block sequence. The black arrow in the left bottom represents the progression of the block, from left to right, starting at the verbal presentation of the first word. The participants first encoded a four word sequence in order presented. Eight rhyming comparisons were made, visualised by the break in the progression of the block (after encoding; bottom right). After the rhyming tasks, the subjects had to recall the words one-by-one via typing on a keyboard provided.

Pre-Processing Pupil Data and Analysis

Pre-processing and analysis was undertook using R software environment (version 4.2.0, R core team, 2021) and JASP (version 0.16.3, Love et al., 2019). We first reconstructed eye blinks and missing data using linear interpolation (Geller et al., 2020) by removing the data 100ms before and after the blink using the gazeR package that contains several functions for dealing with blinks. The data was then down sampled from 1000Hz to 100Hz and aggregated into time bins of certain length (in milliseconds). To convert arbitrary pupil size units to z-scores, we measured the scaling factor by running a short experiment with an artificial pupil and calculated the average pupil size in arbitrary units. The data was baselined using the mean pupil size during the first 50ms after probe onset. It is well established that the minimum latency of the pupil response of approximately 200ms (Ellis, 1981) so the data for the first 50ms should not be influenced. We used a function that finds the median pupil size for the specified period for each trial and performed subtraction correction as default (see Mathôt et al., 2018 for argumentation for median instead of mean). The pupil size distribution was visualized to determine the minimum (z-score of -5) and maximum (z-score of 5), sensibly, so as to exclude the trials in which the baseline pupil size fell outside this range or in the case of missing data. This method was suggested by Mathôt (2018) as the author recommends against removing data based on subject-independent fixed-criterion. The baseline pupil size was then subtracted from all samples. Finally, we aligned the start time with onset of the target (i.e., 3s retention interval after cues onset) rather than the experiment onset.

Cluster-based permutation testing was used to compare the pupil size of the two conditions (cued-bright vs cued-dark) during the window of interest. Permutation testing is a form of nonparametric testing that allows for the control of problems associated with multiple comparison. A permutational analysis of variance returns F-values and p-values based on the explained variance of each factor in the design. These are then used to compute a corrected p-value using Maris & Oostenveld's (2007) cluster mass statistic and were applied to compare pupil size between the two cue conditions (bright vs dark) at each timepoint. The average pupil size of the cued conditions was compared using a paired t-test. The objective was to compare the pupil size difference given a target word (bright or dark) is being attended in verbal WM. An alpha level of .05 was applied throughout the analysis.

Results

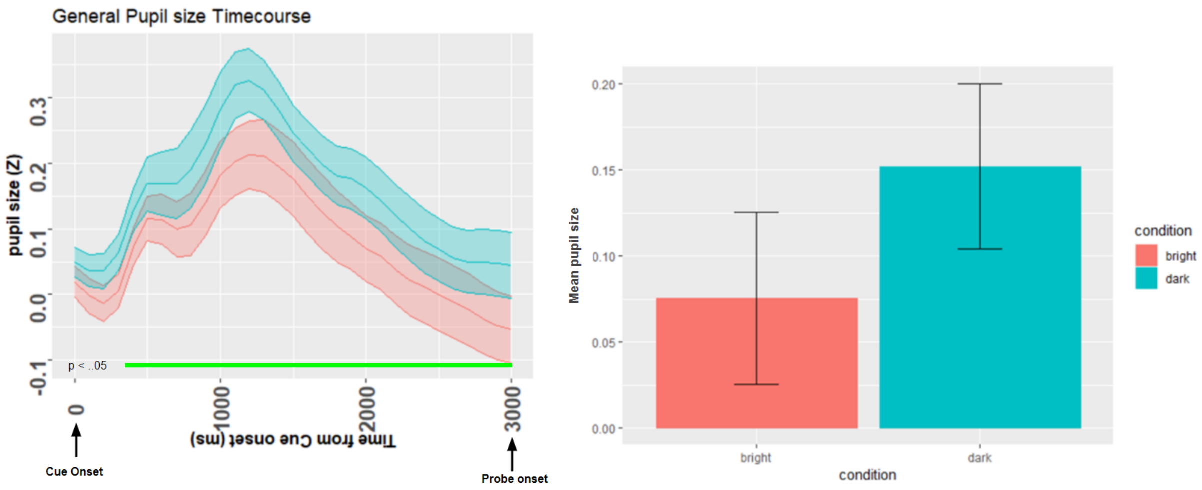
To test top-down modulation of pupillary responses resulting from orientating attention to bright vs dark words in working memory, we compared the pupil size traces directly after the auditory retro-cue. More specifically, we tested whether retrieving (i.e., attending to) a dark word compared to a bright word from a verbal working memory sequence would result in a larger pupil size, on average. The time window of interest was the 3s retention interval after the cue up until just before the presentation of the probe.

Behavioural data revealed the accuracy for the rhyming task was 75%. This accuracy percentage only considers trials in which the bright and dark rhyming task were correct as the other items were deemed unimportant for analysis. This meant, on average, there were 122 valid trials out of 160. The accuracy fell to 56% when we applied the more stringent measure of correct accuracy for the rhyming and recall of dark and bright items. In the latter case, there were, on average, 90 valid trials out of 160 (see appendix B for further discussion).

To compare the two conditions (cued bright vs cued dark) we used a cluster-based permutation which yielded significant differences between the conditions arising at about 460ms after cue onset (figure 2a). To compliment the permutation testing, the average pupil size during the window of interest was calculated. Again, trials in which the rhyming accuracy was correct for bright and dark conditions were used to make this calculation. A paired t-test revealed a significant difference between the dark and bright conditions [*t*(30) = -2.2735, p = .01516, *d* = .4]. Providing evidence that darker items elicited a larger pupil size compared to brighter items (figure 2b). To further validate this finding, a bayes factor was calculated using a bayes t-test. A bayes factor informs the ratio of the likelihood of the observed data occurring under the alternative hypothesis to the likelihood of the observed data occurring under the null hypothesis.

In this instance, the bayes factor indicated (BF10 = 1.769) ‘weak’ (Van Doorn et al., 2021) or ‘anecdotal’ evidence (Wetzel et al., 2011) for the finding that there is a significant difference between dark and bright conditions.

Figure 2(a) *Figure 2(b)*



Note: (a) This graphs shows the pupil traces for both dark (blue trace) and bright conditions (red trace). The green line visualises when the difference between traces becomes significant (around 460ms) at an alpha level of .05. The x-axis represents pupil size (in z-scores) during the time course of the retention interval and the y-axis represents the time course (in milliseconds) of the retention interval. (b) This bar plot represents the difference between the averages of the bright (red bar) and the dark (green) conditions. On the y-axis is pupil size (in z-score units) and the x-axis is indicates semantic category

For exploratory analysis, we investigated the within-subject effects of pupil size at encoding using a repeated-measures ANOVA with WM position (four serial positions at presentation: 1, 2, 3 or 4) and semantic category (bright vs dark) as independent variables. The ANOVA revealed an insignificant interaction between the WM position and semantic category [$F(3, 90) = .709$, $p = .549$, $\eta^2 = .008$]. This means the encoded positions of bright and dark words does not have an effect on pupil size. There was a significant main effect for semantic category [$F(1, 30) = 10.617$, $p = .003$, $\eta^2 = .027$]. This signifies that the semantic category had an effect on the pupil at encoding. Finally, ANOVA revealed a significant main effect for working memory position using the greenhouse-geiser correction (as sphericity was violated) [*F*(1.888, 56.633) = 22.491, p < .001, $\eta^2 = .234$]. Therefore, the spatial positions of the words in presentation caused the pupil size to dilate or constrict at encoding. Likewise, while encoding the words the semantic category caused the pupil size to change.

Discussion

To reiterate, this paper set out to test top-down modulations of pupil size that result from the orientation of attention to darkness- and brightness-related words in verbal working memory. The analysis confirmed both hypotheses posed at the beginning of this paper. Meaning, on average, the pupil will constrict when attending to (i.e., retrieving) an item that conveys a sense of brightness in verbal working memory compared when one attends to an item that conveys a sense of darkness. Alternatively, the pupil will dilate, on average, when one is attending to an items that convey a sense of darkness in verbal working memory compared to when one attends to an items that convey a sense of brightness. Therefore, the pupil size response reveals the content of an attended in verbal working memory, given an item of focus conveys properties of luminance. In other words, the pupil size reflects the content of the attend item in verbal working memory, implying the ability to track or decode what is being attended.

To achieve this novel finding, we employed a auditory retro-cue paradigm (Zokaei et al., 2019; Husta et al., 2019; Fabius at al., 2017) that ensured the exclusion of any possible contamination by presentations or anticipation of stimuli of differential brightness. Allowing this paper to rule out explanations based on perceptual attention mechanisms related to selective encoding or anticipation. Further providing strong evidence in favour of the effect observed. Additionally, this paper used the same words as Mathôt et al., (2019) and, in turn, has further validated the use of these words in a verbal working memory context. This provides evidence for the use of the items in future studies with similar objectives to of this paper. Ostensibly, the finding that the pupil light response serves as a marker of verbal semantic comprehension of luminance (Mathôt et al., 2017) can be extended to a verbal working memory task. Consequently providing a more structured approach to such an observation in the sense that utilizing a WM task implies more engagement with items and their content. Especially with regard to the task employed in this paper where phonological similarities and dissimilarities are scrutinized.

The findings of this paper extend previous similar observations in visual WM to verbal WM. A crucial departure from the effect found in visual WM tasks (Zokaei et al., 2019; Hústa et al., 2019), is the effect is not the result of allocating attention to a direct visual re-representation (i.e., an item seen during the task) but rather suggest the prioritization of an items semantic content that may have stipulated associations in long-term memory. During maintenance in visual WM task, perceptual long-term memory associations (e.g., mental imagery) activate similar sensory areas to visual WM (Yi et al., 2008). It is not out of the question to hypothesize that similar sensory representations that arise during perception (Laeng & Sultulvedt, 2014) and involve the engagement of non-linguistic visual brain areas (Mathôt et al., 2014) are utilized in the comprehension of items which result in the triggering of a pupillary response in verbal WM. This may explain why significant effects in favour of the PLR have been found in both visual and verbal modalities (see Laeng & Sultulvedt, 2014; Mathôt et al., 2017; 2019).

Following this line of reasoning, our results may also have implications for theories about embodiment of language. Theories of language embodiment hold that when one processes a words meaning, one automatically simulates associated sensory inputs (e.g., perception of brightness when you process the word *lamp*) and prepare associated actions (e.g., forming a grip when processing the word *hammering*) (Rueschemeyer et al., 2010). Since the PLR is a reflexive action to actual visual brightness or darkness and we showed that by semantically a processing word that has associations of brightness or darkness can produce a PLR, we can postulate that our findings suggest support for theories concerning the latter prediction (i.e., prepared action) of embodied language.

Hence, one area in which the findings of this paper may be relevant is to the field of psycholinguistics. This paper reveals that the pupil light response is relevant in verbal semantic comprehension of luminant words and, for instance, it could serve as a unique perspective on whether words are processed differently given words are used in a metaphorical (e.g., *"I had no idea, I was kept in the dark")* or real sense (e.g., *"when the sun goes down, it is dark outside")* (Sprenger et al., 2006; Mathôt et al., 2019).

It is inherently obvious in scenarios in which attentional anticipation and confrontation with a perceptual stimulus that an adjustment of the pupil size is a method adaptation to suit environmental conditions (Mathôt, 2018). Modulation of pupil size in response to the allocation of attention to the content of a word in verbal working memory does not offer the same obvious adaptive function as the eyes are not required to access items that exist purely as semantic representations (Zokaei at al., 2019). Rather, it is possible that the adaptation observed in this study is form of sensory recruitment that supports the maintenance of the verbal items in verbal working memory similar to the neural systems that process the sensory characteristics of items during perception (Sreenivasan at el., 2014; Serences, 2016). Therefore, this paper may show sensory recruitment in the outermost and earliest sensory organ, the eye.

In fact, research on sensory recruitment utilizing working memory has shown the attended stimulus can be decoded via the activity signals of relevant sensory regions (LaRocque et al., 2013; Wolff et al., 2014). In other words, while analysing the activity of sensory regions while a subject priorities certain stimulus with luminance content in working memory one may be able to assert which items is being attended. In a similar vein, this paper showed the contents of a verbally attended item in working memory can be decoded and tracked via one of the earliest forms of sensory processing mechanisms, the pupillary light response.

In conclusion, we have successfully demonstrated that semantic comprehension of words associated with brightness, compared to words associated with darkness, can reveal the content of the attended item in verbal working memory through the pupillary light response. We postulate that this effect can serve as a marker for what is at the focus of attention of verbal working and shows recruitment of visual brain areas during language processing.

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Appendix A

Bright words		Dark words		Filler words		Animal words	
lamplicht	(lamplight)	schoorstee	(chimney)	schouwbur	(theater)	aap	(monkey)
glanzend	(shiny)	blinddoek	(blindfold)	gedroomd	(dreamed)	beer	(bear)
daglicht	(daylight)	schaduw	(shadow)	gestrooid	(sprinkled)	duif	(pigeon)
stralend	(radiant)	gordijn	(curtain)	transport	(transportation)	eend	(duck)
schijnen	(to shine)	nachten	(nights)	voordoen	(occur)	ezel	(donkey)
straling	(radiation)	modder	(mud)	leerling	(pupil)	geit	(goat)
zonlicht	(sunlight)	duister	(dark)	kloppen	(to beat)	hond	(dog)
stralen	(shine)	winters	(winters)	hoezeer	(how much)	kat	(cat)
sneeuw	(snow)	somber	(sad)	toetsen	(tests)	kever	(beetle)
zonnig	(sunny)	donker	(dark)	beheer	(management)	konjin	(rabbit)
helder	(bright)	kelder	(cellar)	punten	(points)	kraai	(crow)
zomers	(summery)	winter	(winter)	graan	(grain)	leeuw	(lion)
glans	(shine)	doffe	(dull)	tafel	(table)	muis	(mouse)
witte	(white)	avond	(evening)	juist	(right)	paard	(horse)
lamp	(lamp)	nacht	(night)	nota	(note)	parkiet	(parakeet)
licht	(light)	bruin	(brown)	oom	(uncle)	rat	(rat)
flits	(flash)	zwart	(black)	trui	(sweater)	rund	(beef)
ster	(star)	kuil	(pit)	kip	(chicken)	schaap	(sheep)
wit	(white)	dof	(dull)	jas	(coat)	tijer	(tiger)
zon	(Sun)	hol	(hollow)	lof	(praise)	uil	(owl)

Note: The Dutch words used in this experiment with English translation in brackets

Appendix B

Figure 3(a)

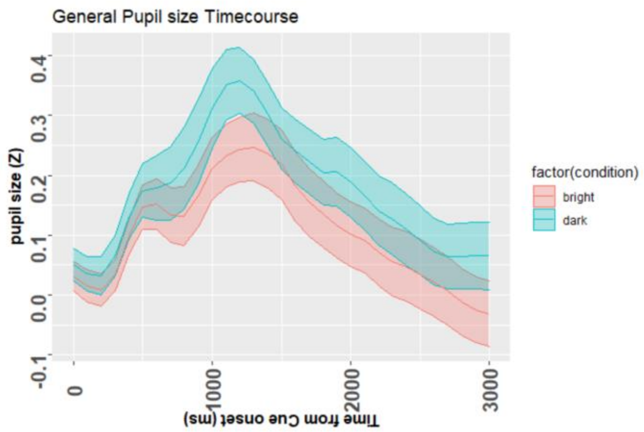
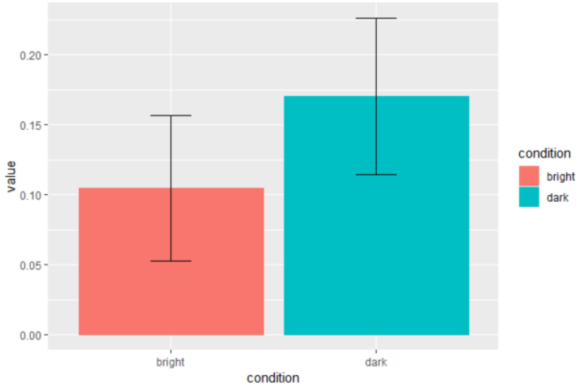


Figure 3(b)



Applying the more stringent requirement of correct accuracy on both rhyme and recall task of bright and dark items the accuracy fell to 56%. A paired t-test under this stringency revealed a nonsignificant difference between the conditions [*t*(30) = -1.4743, p = .07541, *d* = .2] under an alpha level of .05. This stringent requirement was not applied for analysis as correct accuracy on rhyme task implied that the participant correctly attended and retrieved the correct word during the window of interest.