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Elaborato finale

Memoria di Lavoro Visiva per Stimoli Subliminali. Uno Studio Psicofisico.

Visual Working Memory for Subliminal Stimuli. A Psychophysical Study.

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CHAPTER 1

INTRODUCTION

1.1 VISUAL SHORT-TERM MEMORY

The term memory refers to the ability of the mind to remember. In particular, the mind can retain external stimuli learned, such as information and experiences, through the process of recall and recognition.

Among memory systems, the Working Memory (WM) is defined as the system necessary in order to keep things in mind while performing complex tasks such as reasoning, comprehension and learning (Baddeley, 2010).

The WM is divided into three main components: the central executive, an attentional-controlling system; the visuospatial sketch pad, which manipulates visual images; the phonological loop, which stores and rehearses speech-based information (Baddeley, 1992).

In particular, the visual sketch pad maintains in memory items codified from a visual and/or a spatial mode. When the memory retains properties of the original perceptual states generated during the coding process, it can be qualified as a visual memory.

Also, the visual memory has been distinct into three subsystems such as the memory: visual sensory memory, visual short-term memory (VSTM), and long-term memory (LTM). This distinction has an important role in the research field nowadays.

Focusing on the VSTM research field, many researchers have used Baddeley's model of WM, above-mentioned, in which the short-term memory storage system interacts with the central executive and the latter links with LTM, and with motor and perceptual systems. Therefore, the VSTM can be considered as the visual storage component of Baddeley's WM model (Luck & Hollingworth, 2008).

It's possible to distinguish the VSTM from the LTM because the first one has four main characteristics described by Luck and Hollingworth.

The first characteristic is about the speed (20-50 ms/item) with which the VSTM works on coding objects and creating their representations.

In second place, the VSTM has an active neural mechanism which can maintain object representations. This means that when the active maintenance ends also the representations end.

Third, VSTM has a limited capacity composed of only one or two objects for complex stimuli and three or four for the simple ones. Indeed, VSTM stores visual information from a small number of objects, and it happens in an abstract and object-based format. This means that the objects are significantly abstracted away from the precise metric structure of early vision.
Thus, in fourth place, the object representations have indeed limited information. (Luck & Hollingworth, 2008).

1.1.1 How To Study The VSTM

Information from visual perception is abstracted from the visual context by the VSTM, which then creates representations of it and holds it in memory for a short and limited period of time. Measuring these representations created by the VSTM, it is difficult to distinguish the processes from the memory representations while it is easy to change the properties of memorized objects, for this reason the most used research paradigm to study VSTM is the change-detection task (Luck & Hollingworth, 2008).

The change-detection task (Rensink, 2002) has been differentiated into two main types. The first is the one-shot change detection task, in which the subjects have the task of trying to remember a brief sample array that they view and then compare it with the test array presented after a retention interval. The second one is the flicker change-detection task, in which the subjects have to identify the difference between two versions with slight differences and separated by blank periods of an image.

It has been demonstrated that, in the one-shot change detection tasks, the accuracy is almost perfect if the array presents a small number of items. However, the same accuracy will decrease as the number of items increases (Luck & Hollingworth, 2008).

1.2 CONSCIOUS AND UNCONSCIOUS PROCESSING

Understanding the role of consciousness within everyday cognitive functions is one of the most intriguing topics in cognitive psychology and neuroscience (Hassin, 2013). A fundamental distinction in this subject is the one between subliminal priming (or subliminal perception) and unconscious cognition (or unconscious perception), where the first one is a subset of the second one.

In subliminal priming literature the focus is on understanding how stimuli can be processed and influence the behavior when they are not consciously perceived. Instead, in unconscious cognition the unconsciousness is simply discussed theoretically, and the studies examine unconscious processes without limiting themselves to subliminality (Hassin, 2013; Sandberg et al., 2022).

Hassin (2013) proposed the Yes It Can (YIC) principle, whereby basically all high-level cognitive functions (function F) can be deployed without consciousness. In this principle the focus is only on the computational level, one of the three levels of the analysis of the cognitive functions expressed by Marr (Marr, 1982). The computational level explains what the system does and what it does it for. Hassin (2013) also subdivided the cognitive functions into four main groups: cognitive control, goal pursuit, information broadcasting, and reasoning. Looking at the results of these fundamental cognitive functions examined, unconsciousness can perform a function F.

A milder perspective was proposed by Hesselmann and Moors (2015) where some unconscious effects can be criticized due to methodological and theoretical pitfalls. Hassin's literature review is idealized and ignores the current methodological debate on how to study unconscious processing, there is no conflicting evidence reported and empirical studies have not proven evidence in favor of the YIC principle. The authors suggest a "definitely maybe" instead of a "yes it can" dealing with the actual scientific evidence (Hesselmann & Moors, 2015).

In fact, the scientific study of consciousness suffers from several methodological criticisms in terms of consciousness and unconsciousness operationalization (Koch et al., 2016), experimental paradigms (Breitmeyer, 2015) and assessment of the participant experience (Sandberg et al., 2010).

1.2.1 Contrastive Approach

The main methodological approach when it comes to studying consciousness is called contrastive approach (Aru et al., 2012).

The idea is to use some psychophysical-based techniques in order to manipulate the conscious experience. Increasing or decreasing the contrast of a stimulus or reducing the presentation time creates a range of conscious experience from fully unconscious to clearly visible. In this way it is possible to contrast within the same paradigm and with the same stimulus two subjectively different experiences assessing the behavioral and or neural effect. This framework is very flexible and can be applied to several standard cognitive tasks such as perception, attention or memory.

Is important to note that despite the flexibility of the method there are several methodological problems. Firstly, the choice of the consciousness manipulation paradigm can strongly influence the results (for a review see Breitmeyer, 2015). Then, the participant's judgment about the experience can be flawed by response criteria or other nuisance factors. In fact, a lot of studies about unconscious processing have been debated highlighting the critical role of the methodology (Sandberg et al., 2010).

The main method used to detect and measure consciousness is a subjective method called Perceptual Awareness Scale (PAS). In particular, this scale is used to measure to which degree conscious and unconscious processes contribute to a certain performance.

Using PAS, it is assumed that the knowledge about consciousness is possible through introspection because everyone has a privileged access to their own experiences. The original PAS consists of a 4-point scale subdivided as follows:

- No experience (NS): there are no experience of the stimulus, neither the sensation that the stimulus might have been presented.
- Brief glimpse (BG): the subject has the feeling of something have been presented but does not have any clue about what and how was the stimulus.
- Almost clear experience (ACI): the subject has a not very clear experience of the stimulus presented but has some idea about its characteristics.
- Clear experience (CE): the experience of seeing the stimulus clearly.

In order to obtain reliable results, participants have to receive flexible instructions. Therefore, the scale represents how participants experience clarity of perception and helps to obtain precise introspective reports of the participants that are led to interpret the meaning of the scale points. The meaning of each of the four points is thus important to understand the subjective state and compare reports between participants.

The PAS is the most widely used method because it allows measurement of the subject's experience on a trial-by-trial basis and correlates more congruently with objective fairness than other existing scales, this despite being a subjective method and thus liable to participant bias (Overgaard & Sandberg, 2021).

1.2.2 Subliminal Window

A common approach when performing the contrastive analysis and assessing unconscious processing is using the so-called *threshold* stimuli.

The idea is that using a psychophysical adaptive procedure (Leek, 2001) is possible to estimate the subjective threshold i.e. the intensity of a certain stimulus property (e.g., contrast) that is associated with a certain detection performance. In this way, for each participant it is possible to have a certain percentage of visible (i.e., conscious) and invisible (i.e., unconscious) trials. Figure 1 depicts the idea behind the psychophysical threshold estimation.

The aim of the adaptive psychophysical procedure is to estimate the contrast level associated with a certain percentage.

A recent paper by Sandberg and colleagues (2022) noticed that sometimes despite participants reporting unawareness about a certain stimulus, the objective performance (i.e., the unconscious effect) is not constant. In other terms, the same reported experience of unawareness could be associated with a range of performances.

The idea is that if the stimulus feature (i.e., contrast) is higher, but still not associated with a conscious experience, there is more probability to find an unconscious effect. They proposed the concept of subliminal window highlighting that if present unconscious effects should be expected only in certain and limited conditions. Critically, threshold stimuli are, by definition, perceptually weak stimuli, and they might fail to elicit an unconscious above-change behavioral response.

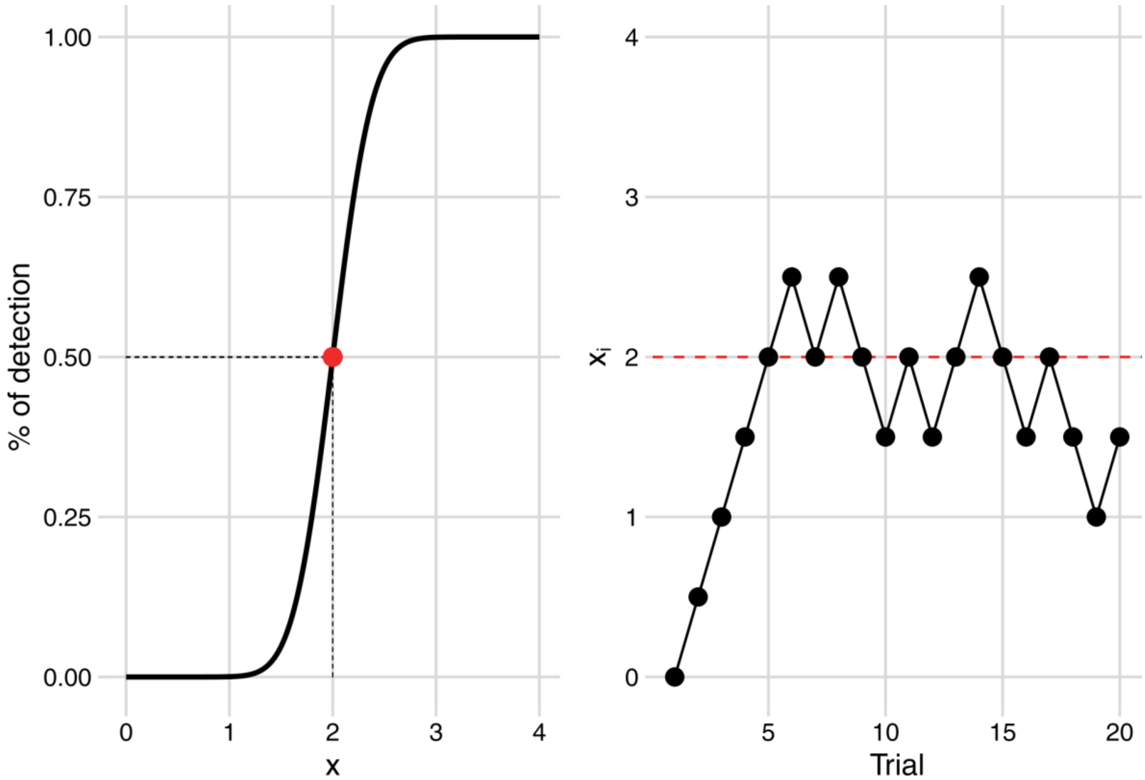

Figure 1. Example of the psychophysical approach. On the left, an estimated psychometric function that maps the detection performance (e.g., the 50% probability of responding "seen") given a stimulus visual property (e.g., contrast). On the right, the staircase procedure used to estimate the 50% threshold.

1.3 WORKING MEMORY AND CONSCIOUSNESS

WM and consciousness have been thought to be closely related to each other (Andrade, 2002). Since the Baddeley's multicomponent model (Baddeley, 1992), along with the Baar's global workspace theory (Baars, 2005), consciousness has been considered a subset of WM and WM has been thought to maintain only information being perceived in a conscious manner. Current research, though, shows that WM is not only a conscious process, but also an unconscious one. Indeed, it is possible to note some evidence of the unconscious process from the studies of implicit WM and studies that combine a WM paradigm with visual masking or attentional blink paradigms (Velichkovsky, 2017).

The first attempt to study the relationship between WM and consciousness was made by Soto and colleagues (2011). They used a change-detection task combined with the contrastive approach presenting a Gabor patch for 17 ms followed by a mask. After roughly 1 s another Gabor was presented, and participants were required to report if the second Gabor was tilted clockwise or anticlockwise compared to the first Gabor. Finally, they reported the visual experience of the first Gabor using the Perceptual Awareness Scale (Overgaard & Sandberg, 2021). After selecting only unseen trials the performance in the WM task was above chance in all conditions. Despite the pioneering attempt and the intriguing result, the methodology has been criticized (Stein et al., 2016). After Soto and colleagues (2011) several other authors tried to replicate and expand the results using a broad range of visual stimuli and paradigms. A recent meta-analysis on the topic (Gambarota et al., 2022) suggests that although moderate and highly heterogeneous the unconscious WM effect seems to be reliable. To note, direct and conceptual replication of Soto and colleagues (2011) failed to find the effect (Taglialatela Scafati, 2019).

The studies also showed that the difference between conscious and unconscious perception takes place in the different activity of frontal and parietal lobes and how their connection with other brain regions spreads (Persuh et al., 2018). For this reason, there are no objections about the possibility of the visual working memory system to store, for a very short time, information being perceived in an unconscious way. This possibility could lead to a reassessment of old theories about consciousness. Even if there's still no clear evidence of an unconscious activity on working memory, there are also possibilities to continue the research trying to demonstrate the unconscious perception of stimuli in visual working memory. Using some techniques such as forced-choice discrimination, visual masking, blindsight or relative blindsight it can be possible the study of this subject. (Persuh et al., 2018)

1.4 STUDY AIMS AND HYPOTHESIS

The main objective of this experiment is to conceptually replicate the Soto and colleagues (2011) paradigm with several improvements. Furthermore, in light of the subliminal window hypothesis (Sandberg et al., 2022), understand if also in the case of visual working memory the unconscious performance could be increased while increasing the objective stimulus properties. In fact, Soto and colleagues (2011) experiments and Taglialatela Scafati (2019) replications actually used a threshold-like stimulus and heterogeneous results could be partially explained by targeting the subliminal window in a non-consistent way.

The hypothesis are:

1. Using a threshold stimulus (i.e., targeting the 50% point on the psychometric curve) should not be associated with an above-chance performance on the WM task
2. Using a stimulus associated with a higher threshold (i.e., > 50%) should increase the performance above the chance level.

CHAPTER 2

EXPERIMENT

2.1 METHODS

2.1.1 Participants

We performed a Monte Carlo simulation in order to estimate the statistical power. The rationale was to consider both the number of trials and the number of subjects in order to find the best trade-off. We adopted a sensitivity-analysis approach where, according to a certain number of trials and subjects, we have a minimum detectable effect size given the desired power level. We simulate data according to a multilevel logistic regression. Figure 2 depicts the power analysis results.

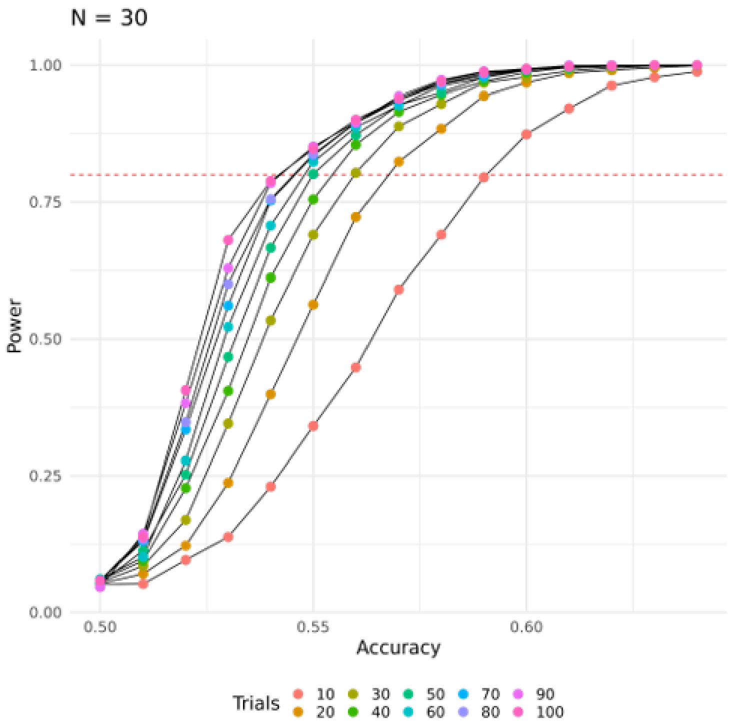

Figure 2. Power analysis results for 30 participants. The x axis represents the effect size (in terms of accuracy), the y axes represent the statistical power and colored points are the number of trials.

We found that with 30 subjects and at least 25 trials in the critical condition (PAS 1 responses) we can detect with 80% power a minimum accuracy of 0.56.

Data were collected from a total of 30 volunteer participants: 23 females (Mean age = 23.3, SD = 1.71) and 7 males (Mean age = 22.9, SD = 1.46). All participants were healthy and with normal or corrected vision.

In order to participate participants signed a written informed consent form in accordance with the ethical principles of the University of Padua before the study took place. It followed a full explanation of the experiment procedure.

2.1.2 Stimuli and Procedure

The experiment took place in a dimly lit room with LG Flatron F700B CRT monitor (diagonal of 17in, 85hz). The viewing distance was 60cm. The paradigm was a standard change detection task combined with a backward masking paradigm (Breitmeyer & Ogmen, 2000). Each trial started with a fixation cross (0.8°) for 500ms, followed by a to-be-remembered Gabor patch (3.4°) for 33ms immediately followed by black and white noise mask (3.4°) for 350ms. The Gabor orientation was randomly selected from a pool of 6 different values: 15°, 45°, 75°, 105°, 135°, and 165°. After 1000ms, another Gabor patch was presented with the same or a different orientation (plus or minus 50°, counterbalanced). The participant had to remember the first briefly presented Gabor and report if the second Gabor had the same or a different orientation using the keyboard.

After the change-detection response, we presented the Perceptual Awareness Scale (Overgaard & Sandberg, 2021) in order to classify each trial according to a subjective visual awareness scale. The PAS has been formulated as follows:

- 1 = I did not see the orientation
- 2 = I have the feeling that I saw the orientation
- 3 = I saw the orientation quite clearly
- 4 = I saw the orientation clearly

In order to present different contrast levels but still having enough unseen trials (i.e., PAS 1 responses) we decided to use a psychophysical staircase procedure. In particular, we used 3 randomly interleaved QUEST (Watson & Pelli, 1983) staircases with different target threshold points: 50%, 65% and 80%. The QUEST is a Bayesian adaptive staircase procedure that trial-by-trial suggests an increasing or decreasing of a certain stimulus property (e.g., the contrast) according to participant responses and the target threshold.

The idea is that instead of choosing arbitrary contrast values or estimating different thresholds before the main experiment, the QUEST procedure controls the stimuli contrast presentation during the experiment for each participant. This clearly increases the contrast variability during the experiment but guarantees an optimal stimuli contrast level for each subject avoiding a time-consuming calibration procedure before the experiment. In addition, given that we do not have previous data to estimate an optimal contrast range, we preferred a data-driven approach. Fixed QUEST parameters were the same for each staircase (gamma = 0, delta = 0.01, beta = 3.5). The QUEST respectively increased the contrast level after a PAS 1 response and decreased the contrast level after a 2-4 response.

For each QUEST staircase we have 6 to-be-remembered Gabors (15°, 45°, 75°, 105°, 135°, and 165°) for the *same* and *different* conditions. Trials in the *different* condition were subdivided in clockwise change (50%) and anticlockwise change (50%). Each unique combination was repeated 5 times for a total of 360 trials. We also added 120 catch trials without presenting the to-be-remembered Gabor. The QUEST was not updated during catch trials. To control the false alarm rate during the experiment we gave feedback during catch trials according to the PAS response. A catch trials followed by a 1 response (i.e., correct rejection) was followed by positive feedback. In other cases, there was a warning message. There was a black screen during the intertrial interval (1500ms) to reduce the Gabor after-effects. The full experiment lasts for roughly 1 hour.

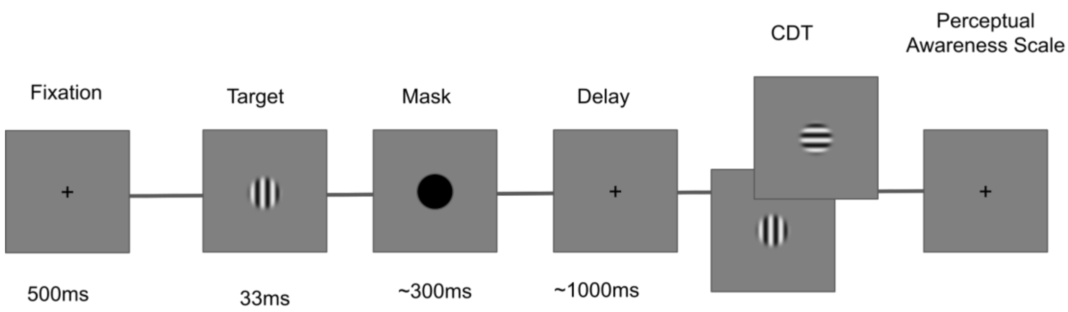

Figure 3. *Paradigm example. Each trial start with a fixation cross for 500ms. Then the target Gabor is presented for 33ms followed by a mask for 300ms. After 1000ms another (same or different) Gabor is presented. The participant had to respond same or different and then report the visual experience of the first Gabor using the PAS.*

2.1.4 Data Analysis

We performed a multilevel logistic regression on PAS 1 trials (excluding catch trials) and the QUEST target level as a predictor. We removed the intercept from the model to directly estimate the accuracy in each condition and test if the accuracy is different from the 50% chance level. We used the R software (R Core Team, 2022) with the *lme4* package to estimate the generalized linear mixed model. Given the repeated-measures design we inserted a random-effect for participants. We used the Wald *z-test* for each model parameter using an alpha level of 0.05.

2.2 RESULTS

The WM accuracy follows a different pattern according to the associated QUEST procedure. Figure x depicts the PAS distribution according to the trial type (catch or valid) and the QUEST target point. Not surprisingly the PAS distribution becomes more right skewed as the contrast increases. Furthermore, the number of PAS 1 trials decrease as the target threshold increases but without completely vanishing, allowing to still compute the accuracy in each condition. This suggests that the overall procedure is working as expected.

As predicted, performance in the 50% threshold condition is at-chance (Odds Ratio = 1.06, 95% CI = [0.95, 1.18], $p = 0.330$). On the other side we found above-chance performance for both 60% (Odds Ratio = 1.19, 95% CI = [1.05, 1.35], $p = 0.006$) and 80% (Odds Ratio = 1.06, 95% CI = [1.03, 1.39], $p = 0.023$) thresholds. Despite the effect being similar between 60% and 80% thresholds, the former has a narrower confidence interval (see the 50% threshold) due to a higher number of trials. For this reason, the 60% condition is more reliable than the 80%.

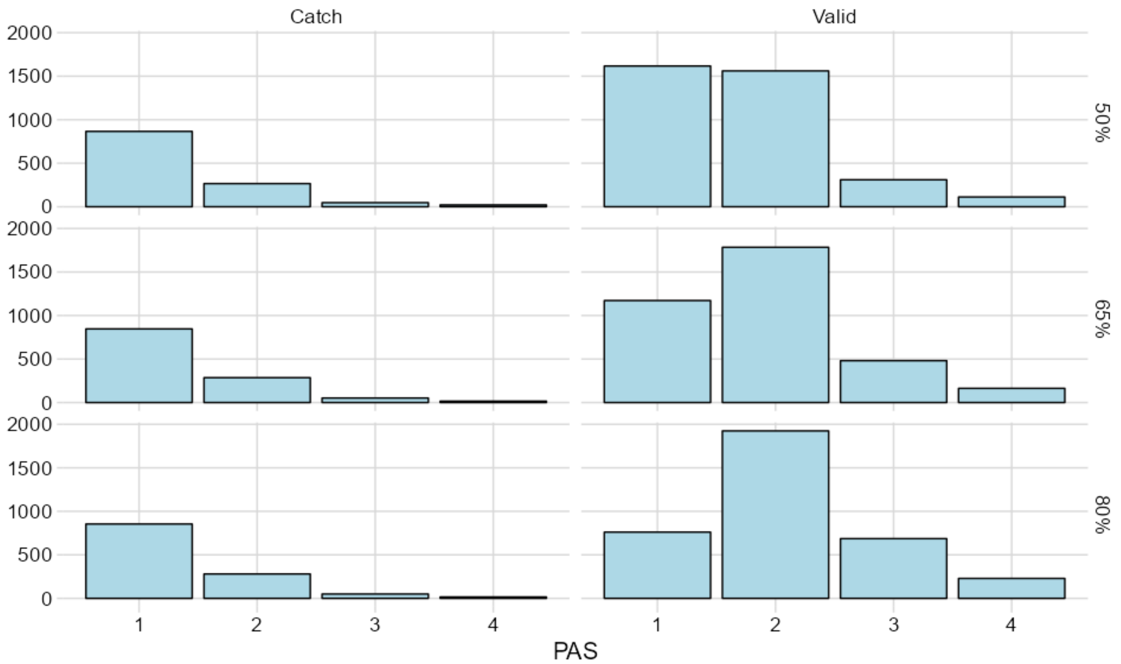

Figure 4. *The PAS distribution according to the QUEST target threshold (50%, 65% and 80%) and the trial type (valid and catch). To note, the QUEST staircase is not updated with for catch trials thus the expected distribution should be the same between different thresholds.*

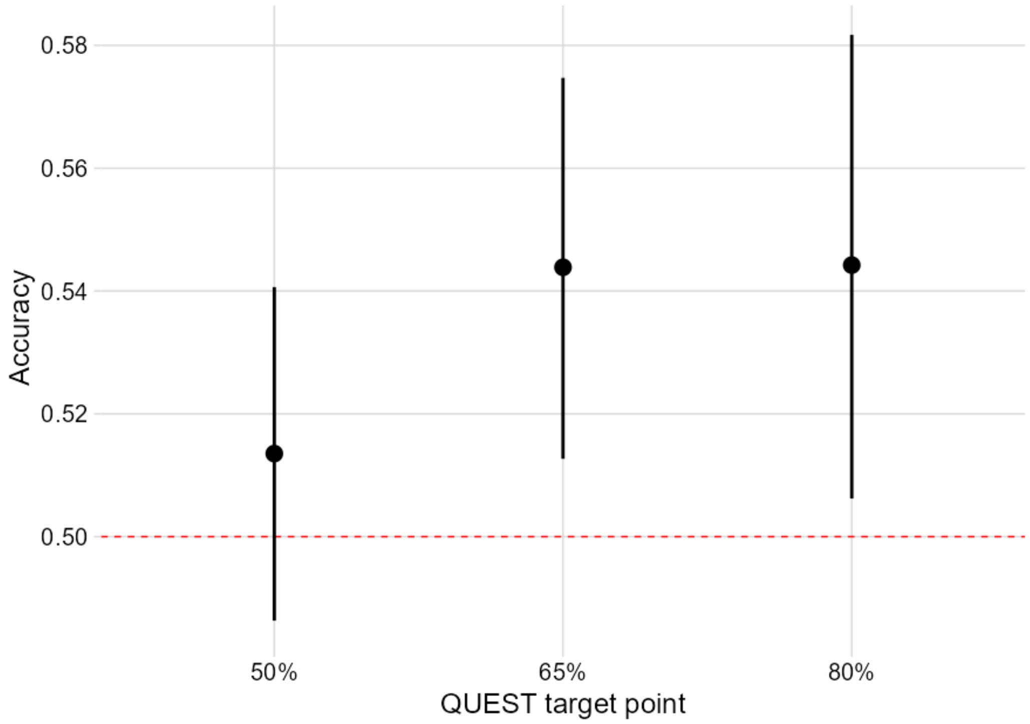

Figure 5. *Results from the Multilevel Logistic Regression. Points and intervals represent respectively the estimated performance with the 95% confidence interval. The dotted red line is the chance level.*

	WM Accuracy		
Predictors	*Odds Ratios*	*CI*	*p*
QUEST 50%	1.06	0.95 – 1.18	0.330
QUEST 65%	1.19	1.05 – 1.35	**0.006**
QUEST 80%	1.19	1.03 – 1.39	**0.023**
Random Effects			
σ^2	3.29		
$\tau_{00\ \text{subject}}$	0.02		
N_{subject}	30		
Observations	3550		

Table 1. *Results from the Multilevel Logistic Regression. Results are presented in odds ratios with the 95% confidence interval (CI) and the Wald z-test p-value. Random effects represent the by-participants variability.*

CHAPTER 3

DISCUSSION

According to what was stated above and considering the 50% threshold, as it is used by many studies in the literature, the performance result is not associated with an above-chance performance on the WM task. This result is not in line with the results of Soto (2011), where the performance was instead above chance in all the conditions tested in the experiment. A possible explanation concerns Soto's sample size and the different methodology adopted in this study. Similarly, from a recent meta-analysis (Gambarota 2022) emerged a lot of heterogeneity in the effects suggesting that, despite a similar aim and methodology, a remarkable range of results can be expected.

By the way, it has been noticed that when an upper threshold is considered (>50%), thus the stimulus contrast is higher, performance exceeds the chance level while remaining relatively low in terms of effect size. This suggests that, even for WM tasks with subliminal stimuli, the presence of the effect might be a function of the physical characteristics of the stimulus (i.e., the subliminal window, Sandberg et al, 2022), in this case the contrast, even though from the participant's perspective the experience is always classified as unconscious.

Nevertheless, this study has some limitations. Although the power analysis suggests that the sample size and number of trials are adequate, increasing the threshold drastically reduces the number of unaware trials with the risk of having large between-subject variability in terms of the number of trials. This aspect cannot be a priori controlled except by increasing the overall number of trials with the risk of an excessive experiment duration.

Also, the use of the PAS could be questioned. The PAS, by definition, makes the participant's evaluation of the experience subject to response bias. This has been mitigated by including catch trials to assess the participants' overall detection strategy. Another limitation is the variability in subjective threshold and the use of adaptive procedures. There are plenty of different psychophysical adaptive procedures with several parameters (see Leek, 2001 for an overview). There is not a gold-standard psychophysical setup especially when the task and the response scale (i.e., the PAS) are not commonly used in standard psychophysics experiments. We decided to use the QUEST with default parameters as one of the most used methods especially for the contrast detection (Watson & Pelli, 1983) but other methods could lead to different results.

In conclusion, thanks to this experiment we showed that, by increasing a physical property of the stimulus that subjects had to memorize (i.e., contrast) and analyzing trials where participants reported no experience of the stimulus, the effect of unconscious working memory emerged for trials associated with a QUEST targeting a threshold above the standard 50%. These findings suggest that future research should consider using higher perceptual thresholds to maximize the probability of finding the unconscious WM effect. Furthermore, it could be also interesting to test a higher number of contrasts to better estimate the subliminal window.

CHAPTER 4

ITALIAN SUMMARY

La memoria visiva a breve termine (VSTM) crea una rappresentazione mentale delle informazioni provenienti dalla percezione visiva che vengono astratte dalla realtà e tenute in memoria per un periodo breve e limitato (Velichkovsky, 2017).

La principale ipotesi a cui questa ricerca tenta di rispondere è se, in compiti di memoria visiva a breve termine, stimoli subliminali possano essere associati a performance sopra il livello del caso.

In merito a questo specifico argomento, sia la letteratura scientifica che la metodologia utilizzata da quest'ultima sono molto eterogenee e discordanti (Gambarota et al., 2021).

Il metodo più utilizzato per misurare la VSTM è il Change-Detection Task (Rensink, 2002), in particolare nel One-Shot Change-Detection Task i soggetti devono ricordare degli stimoli visivi e, dopo un intervallo di ritenzione, confrontarli con degli stumoli di test.

Per studiare, invece, la consapevolezza l'approccio metodologico principale è il Contrastive Approach (Aru et al., 2012), in cui si utilizzano alcune tecniche di matrice psicofisica (e.g., visual masking) per manipolare l'esperienza visiva mantenendo lo stimolo al di fuori della soglia di consapevolezza. Il metodo maggiormente utilizzato per misurare l'esperienza consapevole è la Perceptual Awareness Scale (PAS). Questo strumento richiede al partecipante di classificare ogni trial, da non visibile a chiaramente visibile, a seconda dell'esperienza percettiva (Overgaard & Sandberg, 2021).

Usando tre procedure adattive psicofisiche con diversi valori di soglia target (50% - 65% - 80%) sono state presentate delle Gabor variando il contrasto. In questo modo nello stesso esperimento era possibile avere tre tipologie di esperienza dalla soglia percettiva (50%) a stimoli più chiaramente visibili (65% e 80%).

Seguendo l'idea della *subliminal perception window* (Sandberg et al., 2022) a parità di esperienza visiva (e.g., il partecipante riporta di non aver visto lo stimolo) uno stimolo con, ad esempio, il contrasto maggiore dovrebbe essere associato a performance maggiori.

Questo per rispondere a due ipotesi. La prima, rispetto l'utilizzo di uno stimolo a soglia (50%), il quale non dovrebbe essere associato ad una prestazione superiore al livello del caso nel compito di WM.
La seconda, rispetto all'utilizzo di uno stimolo associato ad una soglia più alta (>50% della curva psicometrica), il quale dovrebbe aumentare la prestazione al di sopra del livello del caso.

In accordo con le ipotesi, con contrasto a livello di soglia percettiva (50%) le performance non erano diverse dal livello del caso, mentre con contrasto intermedio (50%) e alto (80%) è stata riscontrata una performance significativamente sopra il livello del caso.

In conclusione, stimoli riportati dal soggetto come al di fuori della consapevolezza della propria esperienza visiva, possono essere associati ad una performance differente in base alla variazione del contrasto.

La ricerca futura dovrebbe quindi considerare la stimolazione non consapevole non come un fenomeno omogeneo, ma considerare la stimolazione non consapevole anche in base alle proprietà fisiche dello stimolo.

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