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Mnemonic Attention in Analogy to Perceptual Attention: Harmony but Not Uniformity

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Abstract

It is widely accepted that peripheral cues in perception capture attention automatically, while central cues need voluntary control to exert functions. However, whether they differ similarly in working memory remains unclear. The present study addressed this issue through 5 experiments using a retro-cue paradigm with more than two hundred participants. Similar to perceptual attention, we found peripheral cues in working memory (1) were more effective than central cues in low memory-load conditions (Experiments 1 and 2), and (2) they influenced performance much faster than central cues (Experiment 5). Unlike perceptual attention, peripheral cues in working memory (1) did not capture attention to memory representations when they are uninformative (Experiment 3), and (2) could raise confidence ratings (Experiment 4). Taken together, our findings suggest that the effects of spatial cues on memory versus perception are similar but not the same.

Keywords: working memory, covert spatial attention, cue validity, confidence ratings, post-cue delay

Mnemonic Attention in Analogy to Perceptual Attention: Harmony but Not Uniformity

Faced with enormous inputs from the outside world, individuals' attention system only allows limited information to be attended, leaving the rest ignored (Carrasco, 2011) to facilitate perceptual processing. As you can image, our visual attention in real life is easily captured by saliency stimuli (e.g., traffic lights), but calls for efforts to be guided by a goal (e.g., looking at road signs when driving). It has been found that stimulus-driven attention is processed automatically in a way of bottom-up manner, whereas that goal-directed attention is processed voluntarily in a way of top-down control (Corbetta & Shulman, 2002). Under the experimental circumstance, these two different processes are usually manipulated by two types of spatial cues: a peripheral cue or a central cue (Posner, 1980). The former refers to a cue located around the target location in the peripheral field, while the latter is placed in the center of screen.

More recently, attention guided by these two types of spatial cues has been found to boost memory representations as well (Griffin & Nobre, 2003; Landman, Spekreijse, & Lamme, 2003). Specifically, a spatial cue correctly pointing towards the target location even after the memory

display has gone also helps in accessing mnemonic information at that location and then leads to behavioral improvement (Shepherdson, Oberauer, & Souza, 2018; Souza, Rerko, & Oberauer, 2016). This type of cue is usually named the “retro-cue”, and the beneficial effect relative to the no cue condition is accordingly known as the retro-cue benefit. Despite a widely held view that the distribution of spatial attention over internal space is similar to that over external space (Sahan, Verguts, Boehler, Pourtois, & Fias, 2016), it remains unclear whether the retro-cue benefits caused by peripheral and central cues differ in a similar way to perceptual attention. In the current study, we investigated this issue in terms of four aspects which will be explained below.

With regard to perceptual attention, Lu and his colleagues have depicted three mechanisms of spatial attention to explain performance improvement, including signal enhancement, external noise exclusion and a combination of the first two mechanisms. Signal enhancement takes place only when the external noise level is low, while external noise exclusion occurs only at high levels of external noise (Doshier & Lu, 2000; Lu & Doshier, 1998, 2000; Lu, Lesmes, & Doshier, 2002). It has been found that both peripheral and central cues can

facilitate performance via an external noise exclusion mechanism, but only peripheral cues can improve performance via signal enhancement (Lu & Doshier, 2000; Lu et al., 2002), suggesting an advantage of peripheral cues over central cues in the presence of low levels of external noise.

In the case of working memory, the cued item no longer points toward the visible noisy stimuli, instead, it refers to the memory representations in mind. To make this clear, we will replace the term “external noise” with “internal noise” in the remainder when it comes to the manipulations of attention to mnemonic items. Internal noise has been described as a function of memory load (Wilken & Ma, 2004). Increasing memory load has been assumed to associate with increase of neural noise (Bays, 2014), as well as worse WM performance (Oberauer & Lin, 2017; Oberauer, Stoneking, Wabersich, & Lin, 2017). The existent research (e.g., Shimi, Nobre, Astle, & Scerif, 2014) has reported an equivalent benefit for peripheral and central retro-cues at high load (i.e., load 4), which is similar to the perceptual phenomena when external noise was high (Lu & Doshier, 2000). The missing part here is that it is still unclear whether these two types of retro-cues differ under low internal noise (i.e., load < 4). In analogy to those findings in

perceptual attention, we predict that only peripheral retro-cues may cause an advantage over central retro-cues at low load.

Secondly, as mentioned before, the automatic nature of peripheral cues is a critical property to distinguish them from central cues. A typical example is that peripheral cues capture attention even if they are uninformative (Lambert, Spencer, & Mohindra, 1987; Yantis & Jonides, 1990). In light of that, we hypothesize that if peripheral retro-cues capture attention to memory representations in a way similar to peripheral cues in perception, the benefits caused by peripheral retro-cues should remain when cues are uninformative. Contrary to this assumption, previous research (Shimi et al., 2014) observed that beneficial effects already disappeared for peripheral retro-cues with low validity (but still informative) at high load (i.e., load 4), suggesting a voluntary process instead of an automatic process. Nevertheless, we cannot directly extend this finding to the low load, which might display a distinct pattern/mechanism from high load for peripheral retro-cues. Therefore, it is worth clarifying whether peripheral retro-cues may differ from central retro-cues at low load in the present study.

Another difference between central and peripheral cues in perception is that central cues raise confidence ratings whereas peripheral cues do not (Kurtz, Shapcott, Kaiser, Schmiedt, & Schmid, 2017). Since confidence ratings rely on areas of prefrontal cortex (Fleming & Dolan, 2012; Lau & Passingham, 2006) involved in voluntary control, Kurtz et al.'s (2017) study suggests a necessary role of voluntary control in processing central cues. In analogy to this finding, we hypothesize that such pattern should be replicated for both peripheral and central retro-cues if voluntary control only involves in processing central retro-cues. Extant research has indicated the enhancement of confidence on central retro-cue trials (Berryhill, Richmond, Shay, & Olson, 2012), which is consistent with the above hypothesis. In the present study, we investigate the effect of peripheral retro-cues on confidence ratings to obtain a more complete picture of processing peripheral retro-cues.

Fourthly, peripheral cues in perception are found to trigger attentional orientation faster (~100ms) (Liu, Stevens, & Carrasco, 2007; Remington, Johnston, & Yantis, 1992) than central cues (~300ms) (Busse, Katzner, & Treue, 2008). With regard to the retro-cue benefit, to our best knowledge, it usually takes 300-500 ms to show up (Myers, Stokes, & Nobre, 2017; Souza

& Oberauer, 2016; Pertzov et al., 2013; van Moorselaar, Battistoni, Theeuwes, & Olivers, 2015), yet, the question regarding whether peripheral and central retro-cues differently affect the timings of retro-cue benefits is still unclear. In the current study, we address this issue by varying the length of the post-cue delay in both retro-cue conditions. We hypothesize that peripheral retro-cues may access the mnemonic information more quickly than central retro-cues. Specifically, when the cue-to-probe interval is shortened to 100 ms, the retro-cue benefits caused by peripheral cues may remain, but the effects by central cues should disappear.

In sum, we design 5 experiments using the retro-cue paradigm to sequentially test the above hypotheses. In Experiment 1, we investigate a potential difference between peripheral and central retro-cues when memory load is low (i.e. load 2). In Experiment 2, we replicate the results of Experiment 1 and further explore whether the difference between the two retro-cues exists at other memory loads (e.g., load 1, load 3, and load 6). In Experiments 3 and 4, we examine the mechanisms of the retro-cue benefits using uninformative cues (Experiment 3) and confidence ratings after each response (Experiment 4). In Experiment 5, we manipulate the length of the post-cue delay to compare the timings of retro-cue benefits caused by peripheral

and central cues. Table 1 provides an overview of the manipulated variables in each experiment.

Table 1

Overview of the Experiments

Experiment	Sample	Manipulated Variables
Exp.1	$n = 84$ (77)	Cue Type (peri-cue, cent-cue, no cue); Memory Load (load 2 vs. load 4).
Exp.2	$n = 30$ (28)	Cue Type (peri-cue, cent-cue, no cue); Memory Load (load 1, load 2, load 3, load 4, load 6).
Exp.3	$n = 27$ (24)	Cue Type (peri-cue, cent-cue, no cue); Cue Validity(100% vs. 50%).
Exp.4	$n = 39$ (37)	Cue Type (peri-cue, cent-cue, no cue) + Confidence Ratings; Memory Load (load 2 vs. load 4) + Confidence Ratings.
Exp.5	$n = 40$ (36)	Cue Type (peri-cue, cent-cue, no cue); Memory Load (load 2 vs. load 4); Post-cue Delay (0 ms, 100 ms, 900 ms).

Note. The number in the parentheses indicates the number of participants that are included into analysis. peri-cue = peripheral cue; cent-cue = central cue.

Experiments 1A and 1B

In Experiment 1, we recruited two groups of people to perform the same task but in each experiment different measurements (either eye-tracking or EEG) were simultaneously recorded. These data were separately reported in our previous work (Han & Ku, 2019) but that report mainly focused on patterns of neural activity. Here, we combined these two datasets to show an overall behavioral pattern.

Method

Participants

A group of sixty-four students (age= 22.84 ± 2.75 years, 21 male) and another group of 20 students (age= 21.07 ± 2.69 years, 6 male) from East China Normal University (ECNU) participated in Experiment 1A and Experiment 1B, respectively. These two experiments were both approved by the research ethics committee of the ECNU. Written informed consent was provided by all participants prior to the experiment. Each participant was reimbursed with ¥40/h for their participation.

Design

As shown in Table 1, we used a 2×3 within-subjects design, with memory load (load 2 vs. load 4) and cue type (peripheral cue, central cue, and no cue) as factors. Six conditions with the same number of trials were randomly mixed within each block. The dependent variable was calculated as the circular standard deviation of response errors (Raw SD), which remains for all experiments reported here.

Stimuli and Apparatus

The experiment was displayed on a 23.8-inch DELL monitor with a resolution of 1,024×768 pixels (refresh rate 60Hz). Participants were seated at a distance of 63 cm from the monitor. We used Psychtoolbox implemented in MATLAB® to generate white (R=255, G=255, B=255) stimuli on a black (R=0, G=0, B=0) background. A fixation dot (0.24°) was presented in the center of the screen. Each Gabor patch (radius 5°, contrast 100%, spatial frequency 2 cycles/degree) had its center arranged at the corners of a 6.6°×6.6° virtual square centered on the screen. Their orientations in each trial were chosen at random, with the constraint that they differed from each other by at least 10°. The central cue was an arrow (1.8°×1.28°) at the screen center, while the peripheral cue was a dashed circle at the probed location (radius 5°).

Procedure

One sample trial is illustrated in Figure 1. Each trial started with a fixation dot presented for 500 ms, followed by the memory display for another 500 ms. The display consisted of two or four Gabor patches. After a delay period lasting 2,000 ms, a probe with a randomly oriented Gabor patch was presented at the position of one of the patches in the memory array. Subjects were asked to memorize the orientations of Gabor patches and then to recall one of them at test as precisely as possible by rotating the probe using the mouse. In retro-cue trials, either a central cue or a peripheral cue was presented for 100 ms following 1000 ms after the array offset, always pointing to the probed location (100% cue validity). In the no cue trials, the fixation dot remained on the screen during the whole delay period, without any changes to it. The inter-trial interval was 1,000 ms. At the beginning of the experiment, participants were told to maintain central fixation during the first 3,000 ms in each trial and to make use of the retro-cue as much as possible. Participants first completed 20 practice trials to get familiar with the task, and then completed 8 experimental blocks with 72 trials each.

Figure 1

184 *An Illustration of One Sample Trial for Experiments 1 to 5*

185

186 *Note.* Load 2 and load 4 with 100% valid retro-cues were used in Experiments 1, 2, 4 and 5.

187 Another three loads (e.g. load 1, load 3, load 6) were included in Experiment 2. Load 2 with

188 100% and 50% valid retro-cues were used in Experiment 3. Confidence ratings after each

189 adjustment were used in Experiment 4. Post-cue delays (i.e. Delay2) with 0, 100 and 900 ms

190 were used in Experiment 5.

191 **Data analysis**

192 For each condition, response errors were first calculated by subtracting the response

193 angle from the target angle and transferred to the range from -90° to 90° . The circular standard

194 deviation of response errors (Raw SD) was then calculated by means of the CircStat toolbox

(Berens, 2009) implemented in MATLAB®. Seven subjects were excluded from analysis due to missing data (2 persons) or poor performance in at least one condition (i.e. fell outside of 99% confidence interval after Z-transformation, the same criteria as for the following experiments). A 2×3 repeated ANOVA on Raw SD was conducted to quantify the main effects of memory load and cue type, as well as their interactions. Partial eta squared (η_p^2) and Cohen's d were given as measures of effect size. Similar analysis routines were applied in the following experiments.

Results

As shown in Figure 2a, there were significant main effects of memory load ($F(1,76)=492.24, p<0.001, \eta_p^2=0.87$), of cue type ($F(2,152)=75.69, p<0.001, \eta_p^2=0.50$), and a significant interaction between the two factors ($F(2,152)=33.66, p<0.001, \eta_p^2=0.31$).

Figure 2

Raw SD and Median RT results for Experiment 1

Note. Peri = peripheral cue, Cent = central cue, each bar denotes a mean value with its confidence interval, the same below.

Table 2 illustrated post-hoc analysis to explain the significant interaction. Specifically, under the load 2 condition, the Raw SD of the peripheral cue ($M=0.72$, $SD=0.24$) was significantly lower than that of the central cue ($M=0.77$, $SD=0.27$), although both types of retro-cues facilitated the performance compared to the no-cue condition ($M=0.81$, $SD=0.23$). Under the load 4 condition, no difference of the Raw SD was found between the peripheral cue ($M=1.12$, $SD=0.35$) and central cue ($M=1.12$, $SD=0.30$), although both of them were more effective than no cue condition ($M=1.35$, $SD=0.37$).

Table 2

Post-hoc Comparisons Between Cue Type Conditions Under Each Load in the Raw SD for

Experiment 1

Load	Cue Type Comparison	<i>t</i>	Cohen's <i>d</i>	<i>p</i>
Load 2	peri vs. cent	-3.21	0.37	0.002
	peri vs. no cue	-7.29	0.83	<0.001
	cent vs. no cue	-2.71	0.31	0.008
Load 4	peri vs. cent	0.37	0.04	0.711
	peri vs. no cue	-10.39	1.18	<0.001
	cent vs. no cue	-10.14	1.16	<0.001

Note. peri = peripheral cue; cent = central cue, the same as below.

To test whether the advantage of peripheral cues at load 2 was compensated for by slower responses, we performed a control analysis on median reaction times (RT). As shown in Figure 2b and Table 3, the median RTs for peripheral cues under the load 2 ($M=2.06$, $SD=0.66$) were significantly faster than that for central cues under the same load ($M=2.12$, $SD=0.70$), demonstrating a similar pattern to the Raw SD. Thus, the Raw SD difference we reported above cannot be explained by speed-accuracy tradeoff.

Table 3

Post-hoc Comparisons Between Cue Type Conditions Under Each Load in the Median Reaction

Time (RT) for Experiment 1

Load	Cue Type Comparison	<i>t</i>	Cohen's <i>d</i>	<i>p</i>
Load 2	peri vs. cent	-2.91	0.33	0.005
	peri vs. no cue	-13.52	1.54	<0.001
	cent vs. no cue	-11.08	1.26	<0.001
Load 4	peri vs. cent	-2.10	0.24	0.039
	peri vs. no cue	-14.42	1.64	<0.001
	cent vs. no cue	-13.67	1.56	<0.001

Discussion

Experiment 1 examined retro-cue benefits by peripheral and central cues under different memory loads. We observed retro-cue benefits for both types of cues consistent with previous studies under the load 4 condition (Griffin & Nobre, 2003; Gunseli, van Moorselaar, Meeter, & Olivers, 2015; Landman et al., 2003; Pertzov et al., 2013).

Importantly, this experiment found a difference in the size of the retro-cue benefits between central and peripheral retro-cues. In detail, peripheral retro-cues were more effective than central retro-cues under the load 2 but not under the load 4 condition. The control analysis on median RT showed a similar pattern to the Raw SD results, thus excluding the possibility of a speed-accuracy tradeoff. As a result, the advantage of peripheral retro-cues over central retro-cues appeared only when memory load was at low but not high level. In the perceptual domain, Lu and Doshier (2000) found that only peripheral cues but not central cues were effective when

external noise was low, although both of them were effective when external noise was high. In light of these findings, we could summarize attentional effects on both perception and working memory as a function of the noise level: Peripheral and central cues seem to differentiate only when noise is at low level, whereas they seem to be equivalent when noise is at high level. Such convergence suggests a shared mechanism of attentional orienting processes across perception and working memory.

Experiment 2

The main purpose of experiment 2 was to further explore the boundary of the dissociations between central and peripheral cues in working memory. That is, we aimed to identify at which load the dissociation starts to emerge and to disappear. To address this issue, we manipulated the load level over a broader range (i.e. 1, 2, 3, 4, or 6 stimuli). We expected that under the load 1 condition, no difference should be observed between central and peripheral retro-cues as they were not required when there was only one item. As predicted from the noise level hypothesis, and observed in Experiment 1, we expected a difference under

the load 2, whereas no difference should be found under higher memory load (i.e. load 4 and load 6). Finally, we investigated whether the above difference between the two cues remained or disappeared under the load 3 condition.

Method

Participants

A group of 30 participants from East China Normal University (ECNU) participated in the experiment. The experiment was approved by the research ethics committee of the ECNU. All participants signed written informed consent prior to the experiment. Two participants were excluded from further analysis due to poor performance in at least one condition (the same criterion as for the above experiments).

Design

As shown in Table 1, we used a 5×3 within-subjects design, with memory load (load 1, load 2, load 3, load 4 and load 6) and cue type (central cue, peripheral cue, and no cue) as factors. This yielded fifteen conditions which were evenly and randomly mixed within each block.

272 ***Stimuli and Apparatus***

273 The stimuli and apparatus were identical to those used in Experiment 1 except for the
274 following changes. To begin with, there were six instead of four locations for presenting Gabor
275 patches. Two of them were set to the central vertical line, leaving another four Gabor patches
276 on both sides. Second, the radius of the Gabor patches and of the peripheral cues was
277 narrowed down to 3°. Lastly, the distance from the center of each Gabor patch to the center of
278 the screen was fixed at 8°.

279 ***Procedure***

280 The trial sequence was identical to that used in Experiment 1. All retro-cues were 100%
281 valid, meaning that the probe always appeared at the cued position. There were 10 blocks in
282 total and each contained 75 trials. Prior to the formal start, participants performed 20 practice
283 trials to become familiar with the task.

284 ***Results***

As shown in Figure 3a, there was a significant main effect of memory load

($F(4,108)=139.77, p<0.001, \eta_p^2=0.84$), of cue type ($F(2,54)=40.98, p<0.001, \eta_p^2=0.60$), as well

as a significant interaction between these factors ($F(8,216)=5.11, p<0.001, \eta_p^2=0.16$).

Figure 3

Raw SD results for Experiments 2 and 3

The interaction is illustrated in Table 4. Under the load 2, although both peripheral retro-

cues ($M=0.70, SD=0.23$) and central retro-cues ($M=0.77, SD=0.24$) decreased the Raw SD

compared to the no cue condition ($M=0.84, SD=0.28$), peripheral retro-cues yielded lower Raw

SD than central retro-cues. Under the load 4 condition, both types of retro-cues (peri: $M=1.17,$

$SD=0.40$; cent: $M=1.17, SD=0.43$) facilitated the performance compared to the no cue condition

($M=1.46$, $SD=0.47$), but the difference between two types of retro-cues was non-significant.

These findings replicated those in Experiment 1.

Table 4

Post-hoc Comparisons Between Cue Type Conditions Under Each Load in the Raw SD for Experiment 2

Load	Cue Type Comparison	t	Cohen's d	p
Load 1	peri vs. cent	-1.64	0.31	0.113
	peri vs. no cue	-0.65	0.12	0.520
	cent vs. no cue	1.18	0.22	0.247
Load 2	peri vs. cent	-2.58	0.49	0.016
	peri vs. no cue	-4.61	0.87	<0.001
	cent vs. no cue	-2.45	0.46	0.021
Load 3	peri vs. cent	-1.67	0.31	0.107
	peri vs. no cue	-5.42	1.03	<0.001
	cent vs. no cue	-4.22	0.80	<0.001
Load 4	peri vs. cent	-0.001	<0.001	0.999
	peri vs. no cue	-5.48	1.03	<0.001
	cent vs. no cue	-6.38	1.21	<0.001
Load 6	peri vs. cent	-2.05	0.39	0.050
	peri vs. no cue	-3.66	0.69	0.001
	cent vs. no cue	-1.66	0.31	0.110

In addition, under load 1, there was no significant difference among the three cues (peri: $M=0.54$, $SD=0.18$; cent: $M=0.58$, $SD=0.20$; no cue: $M=0.56$, $SD=0.15$). Under load 3 condition, both central and peripheral retro-cues led to significant retro-cue benefits, but no significant difference was found between these two types of retro-cues (peri: $M=0.95$, $SD=0.37$; cent: $M=1.00$, $SD=0.38$; no cue: $M=1.17$, $SD=0.36$). As can be seen, the pattern at load 3 was similar to that at load 4, suggesting that the dissociation observed at load 2 already disappeared at load 3. Under the load 6 condition, peripheral but not central retro-cue decreased the Raw SD compared to the no cue condition, and there was a marginally significant difference between two types of retro-cues (peri: $M=1.45$, $SD=0.44$; cent: $M=1.57$, $SD=0.44$; no cue: $M=1.69$, $SD=0.40$).

Discussion

Experiment 2 showed that the difference in retro-cue benefits between load 2 and load 4 were replicated. That is, there was a consistent distinction between the two types of retro-cues under the load 2 but not the load 4 condition. In this experiment, we included three additional levels of memory load (i.e. load 1, load 3 and load 6) to explore the boundary of the distinction

observed in Experiment 1. Our results indicated that the difference between two types of retro-cues was only reliable at load 2. Therefore, the boundary of the dissociation between them appears to lie between a load of 2 and higher loads.

By now, Experiments 1 and 2 established the dissociation between the two types of retro-cues at load 2. In the following three experiments, we investigated the nature of such a dissociation in analogy to perceptual attention.

Experiment 3

Experiment 3 used a similar procedure to Experiment 1, except for the following modifications. First, we focused on the load 2 condition in which Experiments 1-2 had shown a consistent difference between central and peripheral retro-cues. Second, we included cue validity (100% vs. 50%) as the second factor. Third, we arranged central and peripheral retro-cues in separate blocks, and each was randomly inter-mixed with no cue trials.

The primary advantage of this design is that we could directly explore whether the retro-cue benefit caused by peripheral cues still remains when cues are uninformative (i.e. 50%

validity). Previous findings have shown that peripheral cues in perception attract attention effectively even if they are uninformative, whereas central cues fail to do so (Briand, 1998; Kingstone, Smilek, Ristic, Friesen, & Eastwood, 2003; Posner, 1978), suggesting an automatic nature for processing peripheral cues in perception. In analogy to it, we hypothesize that a similar pattern should be found when retro-cues are 50% valid. Therefore, there should be a significant interaction between cue validity and cue type in the current experiment.

The secondary advantage of our design is that no more mental processes (e.g. task-switching between two types of retro-cues) are needed in this experiment, as each block only contains one experimental condition (i.e. central or peripheral retro-cues with a certain validity) together with the no cue condition (i.e. baseline).

Method

Participants

A group of 27 students (age=21.43±2.18 years, 14 male) from Peking University (PKU) participated in the experiment. The experiment was approved by the research ethics committee of the PKU. All participants signed a written informed consent prior to the experiment. Three

subjects were excluded from analysis due to poor performance in at least one condition (the same criterion as above experiments).

Design

As shown in Table 1, we used a 2×3 within-subjects design, with cue validity (100% vs. and 50% valid) and the cue type (central cue, peripheral cue, and no cue) as factors.

Stimuli and Apparatus

The stimuli and experimental parameters were identical to those used in Experiment 1. We simultaneously measured neural activities with magnetoencephalography (MEG) in this experiment. Relevant findings can be found in another paper (Han & Ku, 2019).

Procedure

Trial sequence was identical to Experiment 1. There were four types of blocks. Each block contained 80 trials: 64 retro-cue trials (either central or peripheral retro-cues) were randomly mixed with 16 no cue trials. In half of blocks, retro-cues always pointed to the probed location (100% valid); in the other half, retro-cues pointed to the probed location with 50% validity. Participants first practiced 10 trials for each type of blocks and then performed 8

experimental blocks with twice for each of four types of blocks. The order of these blocks was counter-balanced across participants.

Results

As shown in Figure 3b, there were significant main effects of cue validity ($F(1,23)=8.57$, $p=0.008$, $\eta_p^2=0.27$), and of cue type ($F(2,46)=9.43$, $p<0.001$, $\eta_p^2=0.29$), but the interaction between these two factors was non-significant ($F(2,46)=1.38$, $p=0.262$, $\eta_p^2=0.06$).

We then investigated cue type differences for each cue validity. As depicted in Table 5, when the cue was 100% valid, peripheral retro-cues ($M=0.65$, $SD=0.18$) led to lower Raw SD than central retro-cues ($M=0.68$, $SD=0.21$) and lower Raw SD than the no cue condition ($M=0.77$, $SD=0.22$). Central retro-cues led to lower Raw SD than the no cue condition. These findings were consistent with the results in Experiments 1 and 2. In contrast, when the cue was 50% valid, there was no significant difference among the three cue types (peri: $M=0.73$, $SD=0.23$; cent: $M=0.74$, $SD=0.22$; no cue: $M=0.78$, $SD=0.21$). That is, the retro-cue benefit disappeared for both central and peripheral retro-cues.

Table 5

377 *Post-hoc Comparisons Between Cue Type Conditions Under Each Cue Validity in the Raw SD*

378 *for Experiment 3*

Cue Validity	Cue Type Comparison	<i>t</i>	Cohen's <i>d</i>	<i>p</i>
100%	peri vs. cent	-2.20	0.45	0.038
	peri vs. no cue	-4.19	0.85	<0.001
	cent vs. no cue	-3.02	0.62	0.006
50%	peri vs. cent	-0.18	0.04	0.859
	peri vs. no cue	-1.35	0.28	0.190
	cent vs. no cue	-1.30	0.27	0.206

379

380 **Discussion**

381 Results from experiment 3 confirmed that when retro-cues were 100% valid, peripheral
 382 retro-cues were more effective than central retro-cues under the load 2 condition. The block-
 383 design in this experiment did not change our main finding observed in Experiments 1 and 2,
 384 suggesting a robust effect.

385 In addition to the replication, we found that when retro-cues were 50% valid, neither
 386 peripheral retro-cues nor central retro-cues improved performance compared to the no-cue
 387 condition. Therefore, peripheral retro-cues in this uninformative case failed to capture attention
 388 to memory representations automatically, which is consistent to the previous finding using the

load 4 condition (Shimi et al., 2014). However, in the perceptual domain, peripheral cues always capture attention no matter what the validity is. These findings altogether indicate that the attention to memory representations versus perceptual attention are similar but not the same, especially that peripheral cues during the delay interval capture attention to memory representations voluntarily, whereas peripheral cues in perception are processed automatically.

Experiment 4

As mentioned above, only central cues in perception can raise confidence ratings, suggesting that voluntary control is necessary in processing central but not peripheral cues (Kurtz et al., 2017). We hypothesize that attention to working memory should replicate this pattern if voluntary control is only needed for processing central retro-cues. To test this hypothesis, we introduced confidence ratings after each response in the present experiment.

Method

Participants

A group of 39 students (age= 21.37 ± 2.58 years, 12male) from East China Normal University (ECNU) participated in this experiment. They signed written informed consent prior to the experiment. This experiment was approved by the research ethics committee of the ECNU. Two participants were excluded from the analysis due to poor performance in at least one condition (the same criterion as above experiments).

Design, Stimuli and Apparatus

All were identical to those used in experiment 1.

Procedure

Trial sequence was identical to that used in Experiment 1, except for one modification: After each recall, subjects were instructed to evaluate how confident they were about their performance with a 1–9 scale. Participants performed 20 trials for practice, and then 8 experimental blocks, each with 72 trials.

Data analysis

For each condition, we calculated mean values of confidence ratings and then performed a 2×3 repeated measures ANOVA on them, similar to the analysis of the Raw SD.

Results

For confidence ratings (see Figure 4a), there were significant main effects of memory load ($F(1,36)=105.80, p<0.001, \eta_p^2=0.75$), cue type ($F(2,72)=48.55, p<0.001, \eta_p^2=0.57$), and interaction between these two factors ($F(2,72)=17.75, p<0.001, \eta_p^2=0.33$). As shown in Table 6, both central and peripheral retro-cues increased confidence ratings at low load (peri: $M=7.36, SD=0.96$; cent: $M=7.35, SD=0.93$; no cue: $M=7.20, SD=0.96$), and such increment was more prominent at high load (peri: $M=6.04, SD=1.24$; cent: $M=6.16, SD=1.24$; no cue: $M=5.56, SD=1.26$).

Figure 4

Confidence ratings and Raw SD results for Experiment 4

Table 6

Post-hoc Comparisons Between Cue Type Conditions Under Each Load in the Confidence

Ratings for Experiment 4

Load	Cue Type Comparison	<i>t</i>	Cohen's <i>d</i>	<i>p</i>
Load 2	peri vs. cent	0.35	0.05	0.726
	peri vs. no cue	3.81	0.63	<0.001
	cent vs. no cue	3.13	0.52	0.004
Load 4	peri vs. cent	-1.74	0.29	0.090
	peri vs. no cue	7.11	1.17	<0.001
	cent vs. no cue	8.23	1.35	<0.001

For Raw SD (see Figure 4b), there were significant main effects of memory load

($F(1,36)=400.04, p<0.001, \eta_p^2=0.92$), of cue type ($F(2,72)=37.71, p<0.001, \eta_p^2=0.51$), and

interaction between these two factors ($F(2,72)=9.72, p<0.001, \eta_p^2=0.21$). We then investigated

cue type differences for each memory load. As shown in Table 7, under load 2 condition, both peripheral and central retro-cues significantly lowered the Raw SD compared to the no cue condition, and there was no significant difference between two types of retro-cues (peri: $M=0.61$, $SD=0.13$; cent: $M=0.60$, $SD=0.12$; no cue: $M=0.69$, $SD=0.13$). This pattern was more prominent under the load 4 condition (peri: $M=1.07$, $SD=0.24$; cent: $M=1.07$, $SD=0.25$; no cue: $M=1.27$, $SD=0.27$).

Table 7

Post-hoc Comparisons Between Cue Type Conditions Under Each Load in the Raw SD for Experiment 4

Load	Cue Type Comparison	t	Cohen's d	p
Load 2	peri vs. cent	0.09	0.01	0.931
	peri vs. no cue	-5.59	0.92	<0.001
	cent vs. no cue	-5.57	0.92	<0.001
Load 4	peri vs. cent	-0.22	0.04	0.831
	peri vs. no cue	-6.10	1.00	<0.001
	cent vs. no cue	-5.97	0.98	<0.001

Notably, we did not see the significant difference between the two retro-cues at low load which had been consistently found in Experiments 1-3. One possible reason is that we

449 additionally introduced confidence ratings in the current experiment, which modulates the
450 results. To examine this idea, we directly compared the current situation with the one in which
451 confidence ratings were not included (i.e., Experiment 1). We calculated the Raw SD difference
452 between peripheral and central retro-cues (i.e., cue-type effect) in Experiments 1 and 4
453 separately, and then performed a 2×2 mixed-design ANOVA on it with rating condition (without
454 rating in Experiment 1 vs. with rating in Experiment 4) and memory load (load 2 vs. load 4) as
455 factors. Results showed a marginally significant interaction between these two factors
456 ($F(1,112)=3.15$, $p=0.079$, $\eta_p^2=0.03$). Independent t -tests further revealed a significant difference
457 in the size of the cue-type effect between the two experiments under the load 2 ($M_{\text{diff}}=-0.05$,
458 $SD_{\text{diff}}=0.03$, $t=-2.03$, $p=0.044$, Cohen's $d=0.40$) but not under the load 4 condition ($M_{\text{diff}}=0.01$,
459 $SD_{\text{diff}}=0.03$, $t=0.382$, $p=0.703$, Cohen's $d=0.08$), suggesting that confidence ratings significantly
460 modulated the Raw SD difference between the two retro-cues only under the load 2 condition.

461 Discussion

The primary purpose of Experiment 4 was to examine whether attention to working memory affects confidence ratings in a similar way as perceptual attention. Accordingly, subjects were required to evaluate how confident they were after each response.

We found that central retro-cues increased confidence ratings, replicating previous findings (Berryhill et al., 2012). Interestingly, peripheral retro-cues in this experiment also raised confidence ratings, different from findings with peripheral cues in perception. This finding provided a complementary evidence to Experiment 3 which denied an automatic nature of attention to memory representations by peripheral cues and further examined a necessary role of voluntary control underlying this process.

Notably, the significant difference between the two retro-cues at load 2 disappeared in the present experiment. To illustrate the role of confidence ratings in modulating this difference, we compared data from this experiment and from Experiment 1 without confidence ratings. The significant difference between the two experiments at low load verified the effect of confidence ratings on modulating the retro-cue differences. But how could this happen? Our previous work (Han & Ku, 2019) suggested that the stronger prefrontal activities of peripheral retro-cues

relative to central retro-cues, the larger behavioral differentiations between the two types of retro-cues. Given that the activations in prefrontal regions have been reported to play a causal role in confidence ratings (Kwok, Cai, & Buckley, 2019), we proposed one possible account that confidence ratings in this experiment may make the prefrontal activities in the central retro-cue task more alike to the peripheral one, and thus led to no difference between the two retro-cues.

Experiment 5

Experiments 3 and 4 together suggested that attention to memory representations guided by peripheral retro-cues need voluntary control to become effective. In experiment 5, we investigated whether the timings of retro-cue benefits were comparable to that of perceptual attention. If so, the advantage of peripheral retro-cues at load 2 might be due to faster processing than central retro-cues. Based on these assumptions, we predicted that the retro-cue benefits by peripheral retro-cues should remain even if the cue-to-probe interval was shortened to 100ms. To explore this possibility, we additionally included the length of post-cue delay as a varied factor. We manipulated this factor at three levels: 0ms, 100ms and 900ms.

Another purpose of this experiment was to explore whether memory would decay (i.e. performance got worse) in the no cue condition. To address this issue, for no cue trials, the length of delay was set to 1s, 1.2s and 2s, matching the 0ms, 100ms and 900ms post-cue delays in retro-cue trials.

Method

Participants

A group of 40 participants (age=22.41 $\pm$ 3.46 years, 16 male) from East China Normal University (ECNU) participated in this experiment. They signed a written informed consent prior to the experiment. This experiment was approved by the research ethics committee of the ECNU. Four participants were excluded from analysis due to poor performance in at least one condition (the same criteria as for the above experiments).

Design

As shown in Table 1, we used a 2 $\times$ 3 $\times$ 3 within-subjects design with the memory load (load 2 vs. load 4), cue type (central cue, peripheral cue, and no cue) and the length of the post-

cue delay (0 ms, 100 ms, and 900 ms) as factors. Eighteen conditions with the same number of trials were randomly mixed within each block.

Stimuli and Apparatus

Stimuli and apparatus were identical to those used in Experiment 1.

Procedure

The procedure was similar to those used in experiment 1 except for the following changes. First of all, there were 20 blocks in total, each with 72 trials. Besides, for retro-cue trials, one-third of them had the shortest post-cue delay (i.e. upon the end of cue, the probe was presented immediately), one-third had the medium post-cue delay (i.e. 100 ms after the cue offset, the probe was presented), and the remaining one-third had the longest post-cue delay (i.e. 900 ms after the cue offset, the probe was presented). Accordingly, for no cue trials, one-third had the short delay for 1s, one-third had the medium delay for 1.2s, and the remaining one-third had the long delay of 2s.

Results

As shown in Figure 5, the main effects of memory load ($F(1,35)=460.45, p<0.001, \eta_p^2=0.93$), cue type ($F(2,70)=13.40, p<0.001, \eta_p^2=0.28$) and length of post-cue delay ($F(2,70)=22.97, p<0.001, \eta_p^2=0.40$) were all significant. The interactions among these three factors were also significant ($F(4,140)=2.84, p=0.027, \eta_p^2=0.08$).

Figure 5

Raw SD results for Experiment 5

First of all, we investigated the timings of retro-cue benefits caused by central and peripheral retro-cues, respectively. As shown in Table 8, central retro-cues at both loads led to the retro-cue benefits only under the post-cue delay of 900ms (load 2: $M_{diff}=-0.10, SD_{diff}=0.13$; load 4: $M_{diff}=-0.27, SD_{diff}=0.29$). Peripheral retro-cues under the load 4 condition also led to a benefit only at the 900ms post-cue delay ($M_{diff}=-0.20, SD_{diff}=0.25$). However, for peripheral retro-

cues under the load 2 condition, a cueing benefit was already observed at the post-cue delay of 0 ms ($M_{\text{diff}}=-0.05$, $SD_{\text{diff}}=0.12$), though not at a delay of 100 ms ($M_{\text{diff}}=-0.02$, $SD_{\text{diff}}=0.14$).

Table 8

Post-hoc Comparisons Between Cue Type Conditions Under Each Load and Each Post-cue

Delay in the Raw SD for Experiment 5

Load	Post-cue Delay	Cue Type Comparison	<i>t</i>	Cohen's <i>d</i>	<i>p</i>
Load 2	0 ms	peri vs. cent	-4.87	0.81	<0.001
		peri vs. no cue	-2.60	0.43	0.014
		cent vs. no cue	2.43	0.40	0.021
	100 ms	peri vs. cent	-3.74	0.62	<0.001
		peri vs. no cue	-0.90	0.15	0.376
		cent vs. no cue	3.66	0.61	<0.001
	900 ms	peri vs. cent	0.94	0.16	0.355
		peri vs. no cue	-3.35	0.56	0.002
		cent vs. no cue	-4.28	0.71	<0.001
Load 4	0 ms	peri vs. cent	-1.67	0.28	0.103
		peri vs. no cue	-0.48	0.08	0.636
		cent vs. no cue	1.37	0.23	0.179
	100 ms	peri vs. cent	-1.44	0.24	0.159
		peri vs. no cue	-0.47	0.08	0.643
		cent vs. no cue	1.01	0.17	0.321
	900 ms	peri vs. cent	2.35	0.39	0.025
		peri vs. no cue	-4.59	0.77	<0.001
		cent vs. no cue	-5.61	0.94	<0.001

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Second, we focused on comparing the Raw SD differences between central and

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peripheral retro-cues for the post-cue delay of 0 ms under each load. As shown in Table 8,

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although no difference of the Raw SD between these two cues was observed under the load 4

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condition, the Raw SD of the peripheral retro-cues ($M=0.73$, $SD=0.20$) was significantly lower

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than the Raw SD of the central retro-cues ($M=0.82$, $SD=0.21$) under the load 2 condition. The

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post-cue delay of 100 ms replicated this pattern (peri: $M=0.73$, $SD=0.22$; cent: $M=0.82$,

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$SD=0.22$).

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Finally, we investigated the main effect of the length of post-cue delay for the no cue

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condition under each load. As shown in Table 9, no significant difference was observed under

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either load 2 ($F(2,70)=1.41$, $p=0.251$, $\eta_p^2=0.04$), or load 4 ($F(2,70)=1.32$, $p=0.28$, $\eta_p^2=0.04$)

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conditions, suggesting no decay of the memory representations for the no cue condition.

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Table 9

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Post-hoc Comparisons Between Post-cue Time Conditions Under Each Load and Each Cue

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Type in the Raw SD for Experiment 5

Load	Cue Type	Post-cue Delay Comparison	<i>t</i>	Cohen's <i>d</i>	<i>p</i>
Load 2	peri-cue	0 ms vs. 100 ms	0.01	<0.001	0.995
		0 ms vs. 900 ms	1.63	0.27	0.111
		100 ms vs. 900 ms	1.48	0.25	0.149
	cent-cue	0 ms vs. 100 ms	-0.16	0.03	0.875
		0 ms vs. 900 ms	5.58	0.93	<0.001
		100 ms vs. 900 ms	5.21	0.87	<0.001
	no cue	0 ms vs. 100 ms	1.37	0.23	0.180
		0 ms vs. 900 ms	0.07	0.01	0.942
		100 ms vs. 900 ms	-1.36	0.23	0.184
Load 4	peri-cue	0 ms vs. 100 ms	-0.06	0.01	0.955
		0 ms vs. 900 ms	3.17	0.53	0.003
		100 ms vs. 900 ms	3.38	0.56	0.002
	cent-cue	0 ms vs. 100 ms	-0.09	0.02	0.927
		0 ms vs. 900 ms	7.57	1.26	<0.001
		100 ms vs. 900 ms	6.22	1.04	<0.001
	no cue	0 ms vs. 100 ms	0.04	0.01	0.971
		0 ms vs. 900 ms	-1.42	0.24	0.166
		100 ms vs. 900 ms	-1.29	0.22	0.205

Discussion

In this experiment, we tested the hypothesis that the time of peripheral retro-cues becoming effective was much faster than that of the central cues, as has been shown before for perceptual attention. Indeed, we found that peripheral retro-cue benefits at load 2 had already

appeared even if the post-cue delay was shortened to 0ms, while central retro-cue benefits were not observed given such a short delay. In addition, our results showed that the advantage of peripheral retro-cues over central retro-cues remained at the same time. These findings altogether supported faster processing for peripheral retro-cues to become effective than central retro-cues.

Importantly, one may argue that the retro-cue benefit caused by peripheral retro-cues at this moment reflected a perceptual rather than a memory effect. That is, peripheral retro-cues may just protect the cued item from probe interference (Makovski, Sussman, & Jiang, 2008; Souza et al., 2016) instead of enhancing memory representations. To test this idea, we subtracted the probe orientation from the response and then computed the Raw SD for that difference for peripheral retro-cue and no cue conditions, respectively. The logic here was if peripheral retro-cues protected the cued item from probe interference, participants were supposed to be more susceptible to the orientation of the probe in the no cue condition. Therefore, we should observe a lower Raw SD centered on probe for no cue than that for

peripheral retro-cue condition. In fact, no significant difference was found between the two conditions and thus we could safely exclude this account.

To find out whether memory trace decays in our experiment, we compared differences between different post-cue delays in the no cue condition. The performance did not get better in case of the short delay at any memory loads, suggesting that no decay of memory happened in our experiment.

Generally speaking, we found that both central and peripheral retro-cues took several 100ms to become effective (consistent with Myers et al., 2017; Souza & Oberauer, 2016). The exception to this rule was the peripheral retro-cues at load 2, which became effective at 0 ms post-cue delay.

In addition, when post-cue delay was set to 900 ms, the same as that used in our previous experiments, the peripheral retro-cues did not show an advantage over central cues at load 2, and central retro-cues were more effective than peripheral retro-cues at load 4. This pattern deviated from the one we observed in Experiments 1-3. So far, we have no good explanation for this failure to replicate our earlier result.

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Meta-analysis across experiments

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Finally, we performed a meta-analysis across all 5 experiments because of the following

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purposes. First of all, we evaluated the overall effects of the Raw SD difference between central

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and peripheral retro-cues at load 2, given its presence in Experiments 1- 3. In addition, we

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evaluated the non-significant effects of the difference at load 4 condition (across Experiment 1,

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2, 4, 5).

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Method

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Data Extraction

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For all 5 experiments we reported here, we extracted statistics (i.e. differences of mean

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and standard deviation between the two kinds of retro-cues, sample size, Pearson correlation

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coefficient between the two cues) at load 2 and load 4, respectively. We conducted this

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operation after merging conditions with different lengths of post-cue delay at each load in

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Experiment 5.

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Data Analysis

601 We performed all meta-analysis in ProMeta 3.0 software using a random-effect model
602 which assumes that the true effect size varied from one experiment to the next. Cohen's d was
603 calculated to measure the effect size.

604 **Results**

605 As shown in Figure 6, the overall effect size of the Raw SD difference between the two
606 kinds of retro-cues was significant at load 2 ($p < 0.001$, see Figure 2a) but not at load 4 ($p = 0.806$,
607 see Figure 2b).

608 **Figure 6**

609 *Illustration of Meta-analysis Results*

Note. Meta-analysis results for load 2 (a) and load 4 (b) condition, respectively; 95% CI = 95% confidence interval.

Discussion

To increase the detecting sensitivity and examine the overall effects, we performed a meta-analysis across all five experiments. Results demonstrated a robust difference between the two kinds of retro-cues at load 2 condition, which was consistent with our findings in each experiment except for Experiment 4. Then, why did such difference at load 2 disappear in

Experiment 4? Given that all visual stimuli were identical across Experiments 1 and 4, we could cautiously attribute it to the confidence ratings which were solely included in Experiment 4. This suspicion was in accordance with the fact of a significant difference between these two experiments at load 2 (see results in Experiment 4). In contrast to load 2, the overall effect size at load 4 was non-significant, confirming the equivalent effect of two kinds of retro-cues at load 4.

General Discussion

The main purpose of the current study was to investigate whether the effects of peripheral and central cues on working memory differ in a similar way to perceptual attention.

In analogy to the finding that peripheral and central cues in perception only dissociate at low level of external noise (Lu, Lesmes, & Doshier, 2002; Lu & Doshier, 2000, 2005), we explored whether these two kinds of cues dissociate during the delay interval of a memory task only when internal noise was low (i.e., load 2). In Experiment 1, we found a significant difference between these two types of retro-cues at load 2 but not at load 4. . Next, we investigated

whether such difference could be replicated at other memory loads in Experiment 2, but found it was limited to the load 2 condition. These two experiments, together with the meta-analysis across all five experiments, demonstrated a similarity between mnemonic attention and perceptual attention in that central and peripheral cues tended to differ when noise was at low but not high level.

Next, we investigated whether the advantage of peripheral retro-cues over central retro-cues at load 2 was an outcome of the automatic process of processing peripheral retro-cues. In Experiment 3, we tested this hypothesis by varying cue validity at load 2, which already showed a significant difference in Experiments 1 and 2. Our result showed no beneficial effects for peripheral retro-cues when they were uninformative (i.e., 50% cue validity). This finding was different from the finding for uninformative peripheral cues in perception which could still capture attention effectively due to the automatic nature (Briand, 1998; Kingstone et al., 2003; Posner, 1978). Therefore, our findings suggested attention to memory representations by peripheral retro-cues was not processed in a purely automatic way.

Now that the automatic process could not explain the advantage of the peripheral retro-cues, would voluntary process do? As the improvement of confidence, which was only found for central but not peripheral cues (Kurtz et al., 2017), indicated the involvement of voluntary control in perceptual attention we introduced confidence ratings in Experiment 4 to investigate whether peripheral retro-cues also need voluntary control to become effective. Our results showed that both central and peripheral retro-cues increased confidence ratings, suggesting a necessary role of voluntary control in attention to memory representations by peripheral retro-cues.

Since both central and peripheral retro-cues need voluntary control to become effective, what's the mechanism underlying the advantage of peripheral retro-cues over central retro-cues at low load? Considering that peripheral cues in perception become effective very quickly (~100 ms), while central take longer time (~300 ms) to be employed (Carrasco, 2011), we then proposed that peripheral retro-cues may become effective faster than central ones. To examine this, we presented the probe at 3 different post-cue delays in Experiment 5. Results showed that the peripheral retro-cue benefits already became effective at cue offset, as well as the

advantage of peripheral retro-cues over central retro-cues at this moment, and thus confirming faster timings for processing peripheral retro-cues.

In a nutshell, the advantage of peripheral retro-cues at load 2 may come from them becoming effective faster. In addition, spatial attention to working memory was similar to perceptual attention in that: (1) central and peripheral cues tended to differ when noise level was high, and (2) the timing that peripheral retro-cues became effective at low load was comparable to that of peripheral cues in perception. In contrast, peripheral cues in working memory differed from those in perception: (1) peripheral retro-cues did not capture attention to memory representations when they were uninformative, and (2) they could raise confidence ratings, suggesting that voluntary control was necessary in leading to retro-cue benefits by peripheral retro-cues.

One important issue remained unclear in the present study is the underlying cognitive mechanisms of the Raw SD difference between peripheral and central retro-cues at load 2 but not at load 4. This finding suggested distinct attentional mechanisms across the two loads. To account for these results, we here proposed a theoretical framework in analogy to the

characteristics of three attentional mechanisms in perception (i.e. signal enhancement, external noise exclusion, a combination of signal enhancement and external noise exclusion).

In perceptual domain, external noise exclusion has been demonstrated at high levels of external noise in the four-location displays (Doshier & Lu, 2000) but not in two-location displays (Lu & Doshier, 1998). Referring to these results, the attentional effects under the load 4 condition (i.e. high internal noise) in the current study is more likely to be attributed to internal noise exclusion than signal enhancement which operates in noiseless displays (Lu & Doshier, 1998).

In addition, Lu and Doshier found that signal enhancement could only account for the attentional effects at low levels of external noise (ref), and such effect took place for peripheral cues but not for central cues (Lu & Doshier, 2000), which was regarded as a dissociation of cognitive mechanisms between the two cues in perception. However, in a later study, researchers (Ling & Carrasco, 2006) used a 2AFC orientation discrimination task in absence of external noise, and they identified attentional benefits also for central cues, suggesting that signal enhancement could also account for the effects caused by central cues. The

disagreement between these two studies may lie in the amount of time given to deploy spatial attention. Ling and Carrasco (2006) used 300 ms, whereas the time was only 150 ms in Lu and Doshier's study (2000). This shorter time may lead to insufficient deployment of attention guided by central cues, which further preclude the emergence of signal enhancement for central cues.

Back to our study, the post-cue delay was set to 900ms in Experiments 1-4, participants were supposed to have enough time to deploy their attention to the cued location, and thus it was plausible to attribute attentional effects caused by peripheral and central retro-cues at load 2 to signal enhancement. Therefore, we proposed that both types of retro-cues facilitated performance via external noise reduction at high load and via signal enhancement at low load. And peripheral retro-cues may enhance target signals much earlier than central retro-cues at low load and thus lead to more benefits.

This framework also accounts for different timings of the retro-cue effects across the two loads observed in Experiment 5. In detail, we found that although peripheral retro-cues at load 2 already became effective at cue offset, the improvement was not observed at load 4 at this moment. Within our framework, peripheral retro-cues at load 2 sharpen the cued orientation as

long as signal enhancement is done ($\leq 100\text{ms}$), whereas these cues at load 4 has nothing to do with the cued orientation until internal noise exclusion is completed ($> 200\text{ms}$). Future research is needed to further investigate the timings of internal noise exclusion for both peripheral and central retro-cues.

For the first time, we proposed that the attentional mechanisms in working memory may differ across memory loads, especially for load 2 and load 4. So far, our framework is just a theoretical model and remains to be proved. Future research using neural recordings could apply multivariate decoding methods (e.g., King & Dehaene, 2014; Trübutschek et al., 2017) to see the change of representations directly. We predict that the brain activities caused by peripheral retro-cues should appear much earlier than that by central retro-cues only under the load 2 but not under the load 4 condition. In general, the current framework is not contradictory to conventional models accounting for the retro-cue effect (Manohar et al., 2019; Souza & Oberauer, 2016) but rather a supplement to them.

In conclusion, mnemonic attention and perceptual attention are similar but not the same, especially for peripheral cues. In the current study, we interpreted the retro-cue effects across

two loads as an outcome of signal enhancement (load 2) or internal noise exclusion (load 4).

We believe the present study will shed light on understanding attentional effects of both memory and perception, encouraging future studies and discussions.

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