Supporting Information

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SI Experimental Procedures

Experiment 1 Practice Session. In order for participants to learn the appropriate sensory-motor mappings before the scanner session, they undertook moderate practice. An experimenter was present with the participant during the practice session to input vocal responses so that online accuracy feedback could be provided for both the AV and VM tasks. Practice was divided into five blocks of trials. The first three blocks were used to familiarize participants with single-task performance and contained 18 VM (block 1), 18 AV (block 2), or 18 mixed single-task (block 3) trials. Block 4 consisted of a random mixture of nine AV, nine VM, and 18 DT trials. The fifth practice block was structured the same as a slow-event related run from the imaging session to familiarize participants with the intertrial interval to be used in the scanner (see below). The practice session took ≈25 min to complete.

For practice blocks 1–4, each trial began with a 2-s prestimulus fixation. Stimuli were then presented for 200 ms, beginning a 4-s response interval. For the trials containing the AV task, this interval was followed by a screen in which the query: "Experimenter: Enter the vocal response (TAY = 1, KOO = 2, DAH = 3 NONE = 4)" was presented at screen center. The experimenter then entered the participant's vocal response, which initiated a 2-s postresponse period during which accuracy feedback was provided. Feedback appeared below the fixation point for the AV task, and above the fixation point for the VM task. If a task was performed correctly, feedback consisted of "Tone/Face task CORRECT!" presented in green, whereas if a given task was performed incorrectly feedback consisted of "oooh – you got the tone/face wrong!" presented in red. The task onset asynchrony (TOA) was 8 s.

Practice block 5 was structured the same as a run from the imaging session and therefore used a TOA of 16.2 s (Fig. 1*A*). A trial began with 12 s of fixation, with the last 2 s including an enlargement of the fixation point to alert participants that the stimuli were imminent (the fixation marker returned to normal size with stimulus offset). Stimuli were presented and responses were collected as per blocks 1–4 (i.e., stimuli were presented for 200 ms, initiating a 4-s response interval), except that the experimenter was not present in the testing room to enter the vocal response and no accuracy feedback was provided. Finally, the response interval in block 5 was followed by a 200-ms post-response period after which the next trial began. Practice was successful at familiarizing participants with the response mappings as indicated by high accuracy (≈90%) by the end of practice.

Experiment 2 Practice Session. Practice was performed for the localizer task of Experiment 2 as in Experiment 1 except for the following modifications. Practice was divided into two single-task blocks of trials. The first block contained 18 VM trials, whereas the second block contained 18 AV trials. The practice session took ≈10 min to complete.

Experiment 3 Practice Session. A practice session, consisting of three blocks and lasting ≈30 min, was performed before the imaging session. The first two blocks were used to familiarize participants with the tasks. These blocks were identical to the fMRI session except that the duration of the prestimulus fixation period was reduced to 2 s and the duration of the poststimulus fixation period was reduced to 5 s. Responses to the auditory task were made by pressing the Z or X key with the left hand, whereas WM encoding probe responses were made by pressing the ">" key if the probe was present in the array or the "?" key if it was not. Block 1 consisted of 10 trials drawn randomly from among the 16 trial types. In block 2, each trial type was presented four times (64 trials), with presentation order drawn randomly. Block 3 was identical to an imaging run to familiarize the participants with intertrial interval used in the scanner (see below).

Experiment 4 Methods. Although Experiment 3 examined the effect of manipulating encoding demands on concurrent decision-making, the goal of the present experiment was to demonstrate that the very same encoding manipulation also impacts visual awareness, as predicted by previous studies (1, 2). To do so, an AB-like behavioral experiment was conducted. The paradigm was similar to the one used in Experiment 3 except that the speeded sound discrimination task was replaced with an unspeeded masked indoor/outdoor scene discrimination task, and three SOAs were used (Fig. S1).

Participants. Fifteen new participants (age 18–30) took part in Experiment 4.

Experimental Overview. Experiment 4 was identical to Experiment 3 with the following exceptions. The auditory task (Task 2) used in Experiment 3 was replaced with a visual scene discrimination task (indoor/outdoor). Scene stimuli were grayscale images subtending 4.7° × 4.7° of visual angle. Indoor and outdoor scenes were presented with equal probability for 83 ms and were followed for 100 ms by a scrambled scene mask (drawn from a separate group of scene stimuli). Masks were created by dividing scenes into a 10 × 10 grid of equal sized squares and randomly intermixing them. Three SOAs between Tasks 1 and 2 were used with equal probability: 450, 800, and 1,850 ms.

Each trial began with a 2-s pretrial fixation period. To alert participants that the stimuli were imminent, fixation doubled in size during the final 500 ms. The encoding array was then presented for 250 ms and was followed immediately by a mask for 100 ms. After an SOA of 450, 800, or 1,850 ms, the scene was presented for 83 ms, followed immediately by a scrambled scene mask for 100 ms. A brief (1.9-s) fixation period followed, after which the probe for Task 1 was presented. Participants had 3 s to make their response to Task 1 before the probe for the scene task ("Indoor/Outdoor?") appeared for 3 s. If the Task 1 probe was present in the WM encoding array, participants pressed the "Z" key, otherwise they pressed the "X" key. Participants pressed the "1" key from the number pad if the Task 2 scene was an indoor scene and the "2" key if it was an outdoor scene. The experiment consisted of five blocks. The first block was practice and consisted of 12 trials. Later, blocks 2–5 each contained 48 trials.

SI Results

Experiment 4: Behavioral Effect of T1 Encoding Load on T2 Awareness. Accuracy of Task 1 was affected by the encoding load, $F(1,14) = 22.7$, MSe = 0.0085, $P < 0.001$: Participants were less accurate when the encoding load was high (87.8%) compared with low (97.1%). There was also a marginal effect of SOA, $F(2, 28) = 3.3$, MSe = 0.0024, $P < 0.06$, with Task 1 accuracy decreasing slightly with SOA (from longest to shortest: 94.3%, 91.1%, 92.0%). Performance on the scene discrimination task (Task 2, for Task 1-correct trials) was influenced by both Task 1 encoding load, $F(1, 14) = 29.9$, MSe = 0.0025, $P < 0.001$, and SOA, $F(2, 28) = 6.2$, MSe = 0.0055, $P < 0.01$. Most importantly, the interaction between encoding load and SOA was significant, $F(2, 28) = 6.5$, MSe = 0.0041, $P < 0.01$: At the shortest SOA, scene discrimination was worse when T1 encoding was high, but this effect of encoding load was no longer present at the longest SOA (Fig. S1). These results indicate that the encoding task used in this experiment is sufficient to block conscious awareness of a concurrent visual stimulus—at least when encoding demands are sufficiently difficult, in addition to postponing concurrent response selection demands (Experiment 3). This result, together with the finding that awareness of T1 is required for T1 encoding to interfere with subsequent target performance (3), suggests that the unified bottleneck identified in Experiments 3 acts as a rate-limiting bottleneck for both decision-making and conscious awareness.

1. Jolicoeur P, Dell'Acqua R, Crebolder JM (2001) The attentional blink bottleneck. *The limits of attention: Temporal constraints in human information processing*, ed Shapiro K (Oxford Univ Press, New York), pp 82–99.
2. Ruthruff E, Pashler H (2001) Perceptual and central interference in dual-task performance. *The limits of attention: Temporal constraints in human information processing*, ed Shapiro K (Oxford Univ Press, New York), pp 100–123.
3. Nieuwenstein M, Van der Burg E, Theeuwes J, Wyble B, Potter M (2009) Temporal constraints on conscious vision: On the ubiquitous nature of the attentional blink. *J Vis* 9:18.1–1–18.14.

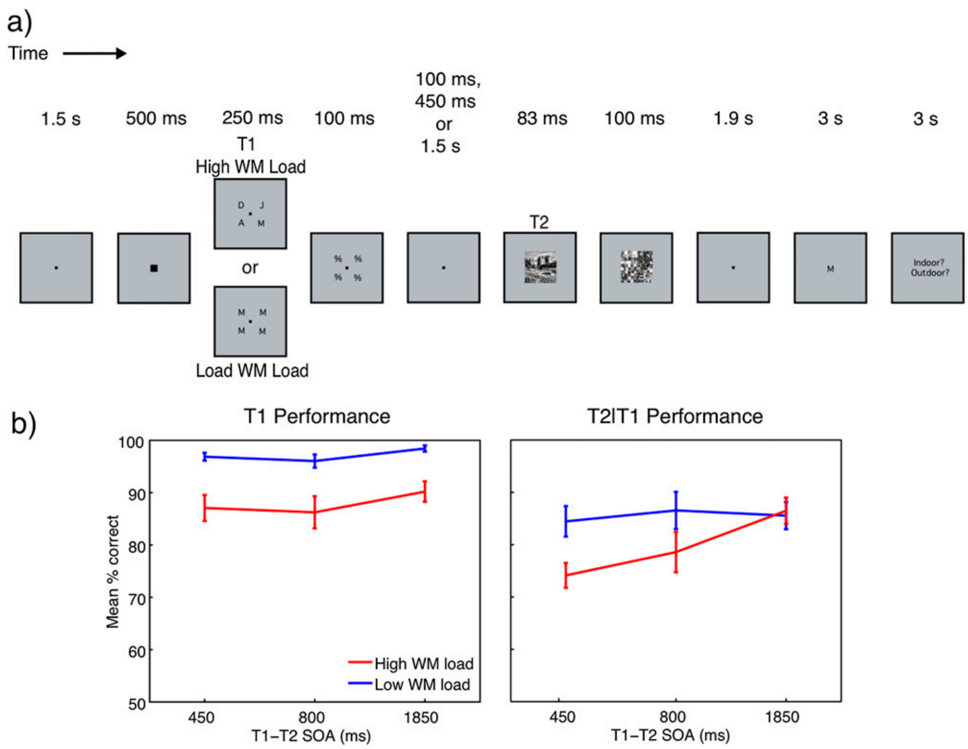

Fig. S1. Experiment 4: Effect of Task 1 encoding load on Task 2 target detection performance (*A*) Task design. The task was similar to that used in fMRI Experiment 3 except that the auditory tone was replaced by a briefly presented indoor or outdoor scene that was masked by a scrambled scene. Two seconds after the second target's onset, subjects had 3 s to respond to T1, followed by another 3-s period to respond to T2. (*B*) Behavioral results: T1 accuracy (*Left*) and T2 accuracy (*Right*) given T1 was reported correctly.

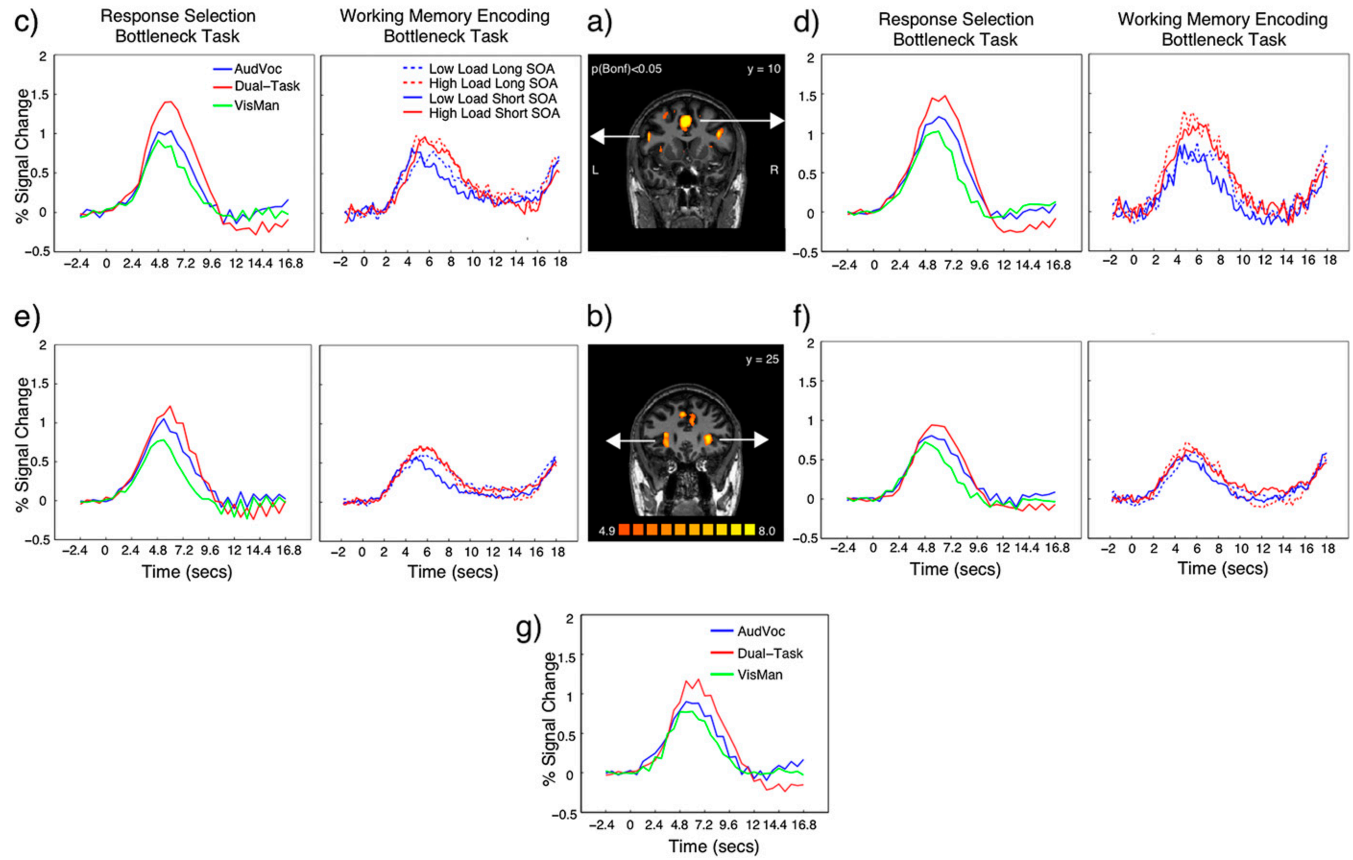

Fig. S2. Noncurve-fitted BOLD time courses for Experiment 1 and Experiment 3. (*A*) Statistical parametric map (SPM) of the conjunction of the AV open contrast and VM open contrast (example subject, Bonferroni corrected SPM shown here for illustrative purposes) showing aSMFC, LIFJ, and RIFJ. (*B*) Left insula and right insula ROIs on the same SPM as above. (*C–F*) BOLD time courses across frontal brain regions for the AV, VM, and Dual-task trials in the response selection bottleneck task (Experiment 1; *Left*) and for the Hybrid encoding/response selection task (Experiment 3; *Right*). (*G*) BOLD time course in left IPS for the AV, VM, and Dual-task trials in the response selection task (Experiment 1).

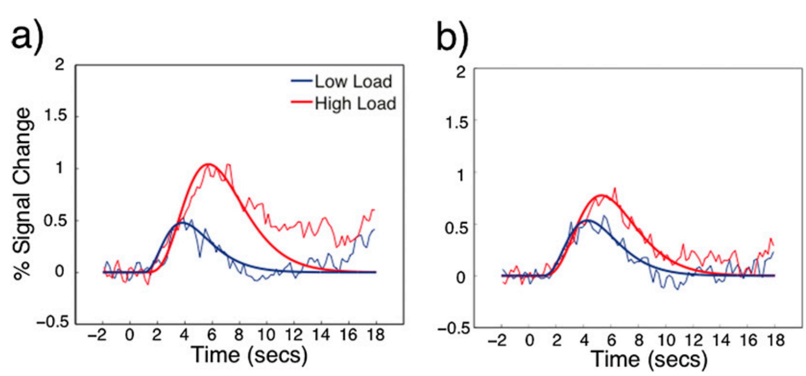

Fig. S3. BOLD time courses in IPS ROIs of Experiment 2. (*A*) Left IPS. (*B*) Right IPS. An encoding load effect was observed in both ROIs.

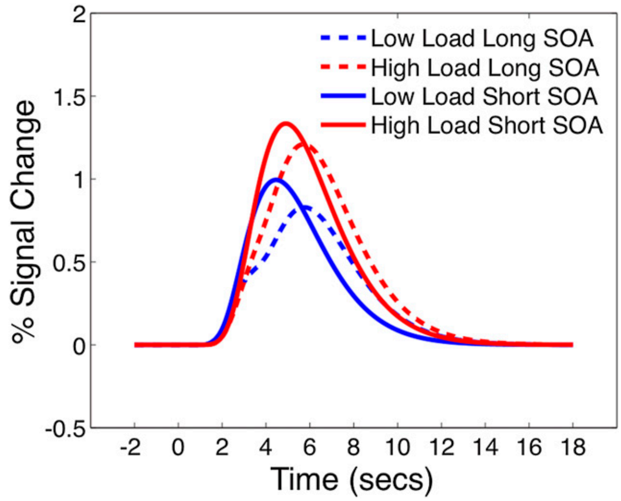

Fig. S4. Predicted hemodynamic responses for Experiment 3. Predictions assuming that the hemodynamic responses reflect both encoding activity of Task 1 and response selection activity of Task 2. The predictions are based on the fits of the observed hemodynamic responses of the bottleneck ROIs (average of left IFJ, left insula, right insula, and pSMFC) for the encoding and response phases of Experiment 2. These two phases provide reasonable estimates of encoding and response selection activity in Experiment 3, respectively: Experiment 2's encoding manipulation was identical to Task 1 in Experiment 3, and Experiment 2's response phase—like Experiment 3's Task 2—consisted of a two alternative discrimination manual response selection. We formed predictions for each of Experiment 3's conditions by summing Experiment 2's encoding BOLD response (high load or low load) and its response selection BOLD response delayed by the amount indicated by Experiment 3's timing structure and behavioral results. For example, in the Short SOA High Load condition, the onset delay of Task 2's response relative to Task 1's was the SOA (250 ms) plus the load effect at that SOA (233 ms) = 483 ms.

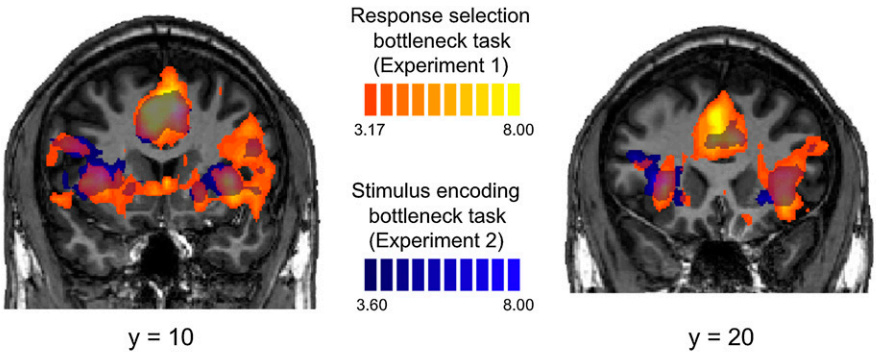

Fig. S5. SPM overlap of Experiment 1 (response selection bottleneck) and Experiment 3 (unified bottleneck). Orange indicates regions conjointly activated by the open contrasts for both single tasks in Experiment 1 (AV and VM). Blue indicates regions activated by the open contrast in Experiment 3. Regions of overlap are shown in purple. Both SPMs are set to q(FDR) < 0.05. Regions associated with the response selection bottleneck in Experiment 1 largely coincide with regions associated with capacity limited perceptual encoding in Experiment 3. Furthermore, no unique regions, at least within the prefrontal coverage used in Experiment 3, were associated with either response selection or with perceptual encoding.

Table S1. BOLD response amplitude and latency measures for the brain regions activated by both single tasks in Experiment 1

ROI	Coordinates	Amplitude: DT vs.		Peak latency: DT vs.		Onset latency: DT vs.	
		AV	VM	AV	VM	AV	VM
aSMFC	0, 12, 41	15*	27*	5.4*	14*	3.6	0.02
L IFJ	−45, 11, 27	22*	26*	5.0*	24*	0.11	0.05
R IFJ	46, 10, 28	15*	22*	2.1	4.2	3.4	1.5
L Ins	−29, 20, 4	7.3*	38*	26*	37*	0.01	0.15
R Ins	32, 20, 2	6.3*	64*	4.8	27*	3.4	3.5
pSMFC	0, 0, 57	8.9*	41*	1.7	13*	3.6	0.02
L FEF	−31, −6, 51	12*	13*	2.9	8.5*	5.6*	0.45
R FEF	31, −5, 50	4.6	10*	1.1	4.6	19*	0.40
L IPS	−31, −59, 43	9.0*	12*	11*	11*	2.3	0.52
R IPS	28, −60, 41	14*	4.8	2.4	2.7	3.3	0.01
L DLPFC	−36, 32, 27	12*	19*	5.4*	3.5	1.1	0.83
R DLPFC	39, 31, 26	6.3*	10*	3.1	8.7*	1.9	0.60

*Significant F values at $P < 0.05$ level. a/pSMFC, anterior/posterior superior medial frontal cortex; L/R IFJ, left/right inferior frontal junction; L/R Ins, left/right insula; L/R FEF, left/right frontal eye field; L/R IPS, left/right intraparietal sulcus; L/R DLPFC, left/right dorso-lateral prefrontal cortex. For each ROI, n = 12.

Table S2. Effect of encoding load in Experiment 2 for the regions associated with the response selection bottleneck in Experiment 1

ROI	*n*	Coordinates	Amplitude (Load effect)	Peak latency (Load effect)	Onset latency (Load effect)
aSMFC	8	−2, 10, 42	13*	34*	1.1
L IFJ	8	−41, 7, 29	9.2*	15*	1.1
L Ins	8	−33, 18, 8	9.7*	16*	0.56
R Ins	9	33, 18, 5	15*	5.7*	0.93
L IPS	9	−29, −58, 41	11*	23*	3.7

*Significant F values at $P < 0.05$ level.

Table S3. BOLD response amplitude and latency measures in Experiment 3 for brain regions showing characteristics of a unified bottleneck associated with the response selection bottleneck in Experiment 1 and perceptual encoding in Experiment 2

ROI	*n*	Amplitude			Peak latency			Onset latency		
		Load	SOA	Load × SOA	Load	SOA	Load × SOA	Load	SOA	Load × SOA
aSMFC	12	9.9*	0.14	0.50	2.2	0.79	6.0*	2.9	0.46	0.02
L IFJ	12	6.5*	0.47	0.21	16*	2.7	11*	2.6	0.13	0.39
L Ins	11	6.5*	0.22	0.78	2.9	9.8*	40*	0.66	2.4	2.9
R Ins	12	3.6	1.1	0.98	1.2	7.3*	12*	0.18	0.21	1.4

*Significant F values at $P < 0.05$ level.

Table S4. Peak latency differences across conditions for Experiments 1–3

	Experiment 1		Experiment 2	Experiment 3		
ROI	DT − AV	DT − VM	Load	Load	SOA	Load × SOA
aSMFC	273 ± 128	668 ± 181	757 ± 129	321 ± 217	219 ± 247	926 ± 379
L IFJ	280 ± 128	625 ± 128	1,055 ± 271	577 ± 145	429 ± 262	762 ± 233
L Ins	388 ± 76	868 ± 143	976 ± 241	275 ± 161	463 ± 148	1,385 ± 218
R Ins	264 ± 120	776 ± 150	584 ± 246	147 ± 134	358 ± 133	871 ± 255
pSMFC	216 ± 165	710 ± 196	637 ± 353	—	—	—
L IPS	485 ± 147	692 ± 211	1,900 ± 396	—	—	—
R IPS	351 ± 225	433 ± 264	—	—	—	—
R IFJ	204 ± 140	501 ± 246	—	—	—	—
L DLPFC	182 ± 78	373 ± 200	—	—	—	—
R DLPFC	228 ± 129	443 ± 150	—	—	—	—

Differences measured mean ± SEM in milliseconds. Load, high load – low load; SOA, long SOA – short SOA; Load × SOA, Short SOA(high load – short load) – Long SOA(high load – short load).