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1 *Full manuscript title*

2 **Independent attention mechanisms control the activation of**
3 **tactile and visual working memory representations**

4

5 *Running title*

6 **Independent attention mechanisms for tactile and visual working**
7 **memory**

8

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13

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15

16 **Keywords**

- 17 • Working memory (WM)
- 18 • Selective Attention
- 19 • Multisensory (tactile / visual)
- 20 • Electroencephalography (EEG)

21 **Abstract.** Working memory (WM) is limited in capacity, but it is controversial whether these
22 capacity limitations are domain-general or are generated independently within separate
23 modality-specific memory systems. These alternative accounts were tested in bimodal
24 visual/tactile WM tasks. In Experiment 1, participants memorized the locations of
25 simultaneously presented task-relevant visual and tactile stimuli. Visual and tactile WM load
26 was manipulated independently (1, 2 or 3 items per modality), and one modality was
27 unpredictably tested after each trial. To track the activation of visual and tactile WM
28 representations during the retention interval, the visual and tactile contralateral delay activity
29 (CDA and tCDA) were measured over visual and somatosensory cortex, respectively. CDA
30 and tCDA amplitudes were selectively affected by WM load in the corresponding (tactile or
31 visual) modality. The CDA parametrically increased when visual load increased from 1 to 2 and
32 to 3 items. The tCDA was enhanced when tactile load increased from 1 to 2 items, and
33 showed no further enhancement for 3 tactile items. Critically, these load effects were strictly
34 modality-specific, as substantiated by Bayesian statistics. Increasing tactile load did not affect
35 the visual CDA, and increasing visual load did not modulate the tCDA. Task performance at
36 memory test was also unaffected by WM load in the other (untested) modality. This was
37 confirmed in a second behavioral experiment where tactile and visual loads were either two or
38 four items, unimodal baseline conditions were included, and participants performed a color
39 change detection task in the visual modality. These results show that WM capacity is not
40 limited by a domain-general mechanism that operates across sensory modalities. They
41 suggest instead that WM storage is mediated by distributed modality-specific control
42 mechanisms that are activated independently and in parallel during multisensory WM.

44

45 **Introduction**

46 Working memory (WM) refers to the ability to memorize stimuli over brief periods of
47 time. The most notable feature of WM is its limited capacity, as only 3-4 items can be
48 successfully maintained in WM (Cowan, 2001; Vogel & Machizawa, 2004). The reasons for
49 these capacity limitations are still under dispute. They may either arise at a central domain-
50 unspecific level, or may be generated independently within separate domain-specific storage
51 systems that represent a particular type of information (e.g., visual, auditory, or tactile items).
52 The domain-unspecific account assumes that the limited capacity of WM reflects the limited
53 availability of an attention resource that is shared across sensory modalities, and/or the
54 existence of a central storage system (Cowan, 2011). In this case, the same capacity
55 limitations would apply regardless of whether memorized items have been encoded through
56 the same modality or through different modalities. Alternatively, if the maintenance of items
57 from different modalities is mediated by distributed processes that operate independently at
58 peripheral modality-specific levels (Tamber-Rosenau & Marois, 2016), WM capacity limitations
59 should occur within – but not across – sensory modalities.

60 The question whether WM capacity limits arise at domain-general or domain-specific
61 levels can be tested in multimodal dual-task experiments, where participants simultaneously
62 memorize sets of stimuli from different modalities (e.g., visual and auditory items), and dual-
63 task interference (i.e., performance decrements in one modality due to WM load increments in
64 another modality) is measured. Crossmodal interference effects were found in numerous
65 auditory-visual experiments (Cocchini, Logie, Della Sala, MacPherson, & Baddeley, 2002;
66 Cowan, Saults, & Blume, 2014; Fougne & Marois, 2011; Morey & Cowan, 2005; Salmela,

67 Moissala, & Alho, 2014; Sauls & Cowan, 2007), but the theoretical implications of such effects
68 remain disputed. Some authors have interpreted interference as evidence for a WM store
69 and/or attention mechanism that is shared across sensory modalities (Cowan, 2010; Cowan,
70 2011; Cowan et al., 2014; Sauls & Cowan, 2007). Others assume that interference in
71 multimodal WM tasks does not reflect a cognitive bottleneck that is specific to WM storage, but
72 instead results from general dual-task coordination costs (e.g., Cocchini et al., 2002). The
73 amount of interference between items from different modalities also varies considerably across
74 previous studies. Experiments that found strong interference led to the conclusion that WM
75 maintenance is mediated by a central mechanism (Sauls & Cowan, 2007), whereas studies
76 that only found weak interference (Cocchini et al., 2002), or no interference at all (Fougnie,
77 Zughni, Godwin, & Marois, 2015), suggest that WM maintenance relies on processes that are
78 inherently modality-specific. A third possibility is that WM capacity is constrained by both
79 central and modality-specific mechanisms (Cowan et al., 2014; Fougnie & Marois, 2011).

80 Evidence that modality-specific mechanisms underpin WM maintenance comes from
81 neuroimaging studies showing that stimulus representations are stored in the same cortical
82 areas that have encoded these stimuli into WM (“sensory recruitment hypothesis” Emrich,
83 Riggall, LaRocque, & Postle, 2013; Jonides, Lacey, & Nee, 2005; Pasternak & Greenlee,
84 2005). Modality-specific sources of WM capacity limits were identified by studies that predicted
85 visual WM capacity based on the size of primary visual cortex (Bergmann, Genc, Kohler,
86 Singer, & Pearson, 2016), or by the amplitude of the contralateral delay activity (CDA, e.g.,
87 McCollough, Machizawa, & Vogel, 2007; Vogel & Machizawa, 2004) over visual cortex. The
88 CDA component emerges in the EEG over posterior visual areas during the retention period of
89 lateralized visual WM tasks. The somatosensory analogue of the CDA has recently been

90 identified in tactile WM experiments (Katus & Eimer, 2015; Katus & Müller, 2016; Katus,
91 Müller, & Eimer, 2015b). During the maintenance of lateralized tactile stimuli, a tactile CDA
92 component (tCDA) is elicited with a topographical distribution over somatosensory cortex.
93 Thus, the CDA and tCDA reflect the activation of WM representations in modality-specific
94 visual and somatosensory cortical areas, respectively. Because both components are sensitive
95 to WM load and WM capacity limits (Katus, Grubert, & Eimer, 2015a; Vogel & Machizawa,
96 2004), co-registering them in bimodal visual-tactile WM tasks allows for testing whether WM
97 capacity limitations are shared across sensory modalities, or whether they arise independently
98 within modality-specific storage systems. The simultaneous measurement of the tCDA/CDA
99 components in tactile/visual WM tasks (Katus & Eimer, 2016; Katus, Grubert, & Eimer, 2017) is
100 feasible after transforming EEG data to current source densities (CSDs, Tenke & Kayser,
101 2012). Combining behavioral and EEG measures in investigations of WM capacity limits is
102 important because behavioral performance may reflect not only WM storage but also other
103 capacity-unrelated processes, such as the comparison between memorized and test items
104 (Awh, Barton, & Vogel, 2007). In contrast, CDA components provide on-line measures of WM
105 maintenance that are unaffected by subsequent memory comparison or response selection
106 processes. A pattern of results where crossmodal interference effects are observed for
107 performance but not for visual and tactile CDAs would therefore suggest that these effects
108 were generated at later storage-unrelated stages.

109 In Experiment 1, participants performed a lateralized dual-task where visual and tactile
110 items were presented simultaneously in the left and right visual field and to the left and right
111 hand. All items on one side had to be memorized, and WM load was manipulated orthogonally
112 in vision and touch. The critical question was whether the maintenance of visual and tactile

113 items in WM is mediated by a shared central process, or by independent modality-specific
114 mechanisms. A recent behavioral dual-task experiment that required memory for visual colors
115 and auditorily presented digits found no crossmodal interactions (e.g., Experiments 1-7 in
116 Fougnie et al., 2015), consistent with the assumption that maintenance operates in a modality-
117 specific fashion. However, such processes might operate independently for different types of
118 content within each modality (Fougnie & Alvarez, 2011; Shin & Ma, 2017; Wheeler &
119 Treisman, 2002). For this reason, Experiment 1 employed a multisensory WM task where
120 participants memorized spatial locations in vision and touch. Although locations are
121 represented in different formats in these modalities (retinotopic or spatiotopic in vision,
122 somatotopic in touch), combining visual and tactile spatial WM tasks may still increase the
123 representational overlap between multisensory information in WM (Tamber-Rosenau & Marois,
124 2016) relative to situations where different feature dimensions have to be memorized in
125 different modalities.

126 On each trial, participants had to memorize the locations of 1, 2, or 3 visual items, and
127 of 1, 2, or 3 tactile items, and memory was unpredictably tested for either modality after the
128 trial. This design allowed us to simultaneously test the effects of increasing WM load within
129 and across modalities on behavioral and electrophysiological measures of WM storage. The
130 number of visual or tactile items that have to be retained should affect performance on trials
131 where the respective modality is tested, with a reduction in accuracy with increased WM load.
132 Increasing visual and tactile WM load should also be reflected by CDA and tCDA amplitudes.
133 Previous unimodal studies have found load-dependent CDA enhancements for set sizes up to
134 3 visual items (Vogel & Machizawa, 2004), and tCDA enhancements for load increments from

135 1 to 2 tactile items (Katus et al., 2015a). Similar modality-specific load effects should also be
136 found in Experiment 1.

137 The critical question was whether in addition to these modality-specific effects, there
138 would be additional costs associated with the manipulation of WM load in the other modality.
139 Domain-general accounts (e.g., Cowan, 2011; Saults & Cowan, 2007) assume that the
140 capacity of visual and tactile WM is limited by a shared central mechanism, and that the
141 capacity limit of 3-4 items found for unimodal WM (Cowan, 2001; Vogel & Machizawa, 2004)
142 also determines the maximum number of items that can be simultaneously maintained in
143 multisensory WM tasks. If this is correct, behavioral and electrophysiological crossmodal load
144 effects should be observed in Experiment 1 when more than 3-4 multisensory items have to be
145 memorized simultaneously. When vision is tested, WM performance should differ as a function
146 of the number of tactile items that are simultaneously maintained, with crossmodal costs on
147 trials with higher tactile load. Analogous crossmodal costs of increased visual load should be
148 observed on trials where tactile WM is tested. In addition, visual CDA components should be
149 affected by concurrent tactile WM load, with reduced components when tactile load is
150 increased, and vice versa for tactile CDA components and visual load. In contrast, if the
151 maintenance of visual and tactile WM representations operates in an entirely modality-specific
152 fashion, no such crossmodal interference effects should be observed. Load manipulations in
153 vision and touch should produce strictly modality-specific behavioral and electrophysiological
154 effects, but there should be no impact of visual load on tactile WM performance and tCDA
155 components, and no effect of tactile load on visual WM performance and CDA components.
156 Because this domain-specific account predicts crossmodal null effects that cannot be
157 confirmed by conventional significance tests (which only allow for rejecting the null

158 hypothesis), we assessed the statistical reliability of null effects using Bayesian statistics
159 (Rouder, Morey, Verhagen, Swagman, & Wagenmakers, 2017; Rouder, Speckman, Sun,
160 Morey, & Iverson, 2009).

161

162 **Experiment 1**

163

164 **Materials and methods**

165 **Participants** The sample size was 30 participants (average age 28y, 19 female, 28 right-
166 handed) after exclusion of 4 participants with excessive EEG artefacts. All participants were
167 neurologically unimpaired and gave informed written consent prior to testing. The experiment
168 was conducted in accordance with the Declaration of Helsinki, and was approved by the
169 Psychology Ethics Committee, Birkbeck, University of London.

170

171 **Stimulus material** Participants were seated in a dimly lit recording chamber with their hands
172 covered from sight. All stimuli were presented for 200 ms. Tactile stimuli (100 Hz sinusoids,
173 intensity 0.37 N) were delivered by eight mechanical stimulators that were attached to the left
174 and right hands' distal phalanges of the index, middle, ring and little fingers. The stimulators
175 were driven by custom-built amplifiers, controlled by MATLAB routines (The MathWorks,
176 Natick, USA) via an eight-channel sound card (M-Audio, Delta 1010LT). Headphones played
177 continuous white noise to mask any sounds produced by tactile stimulation. Visual stimuli were
178 shown at a viewing distance of 100 cm against a dark grey background on a 22 inch monitor
179 (Samsung SyncMaster 2233; 100 Hz refresh rate, 16 ms response time). Throughout the

180 experiments, the monitor showed black crosshairs (three lines at 0°, 45° and 90° polar angle;
181 horizontal/vertical eccentricity: 3.44° of visual angle) and three concentric black rings around
182 the fixation dot (eccentricity: 3.15° outer ring, 2.21° middle ring, 1.26° inner ring); see Figure 1.
183 Stimuli shown on different rings had different sizes, which decreased from lateral to medial
184 (0.40°, 0.34°, 0.28° for stimuli on the outer, middle and inner ring, respectively). A headset
185 microphone recorded vocal responses (“a” for match and “e” for mismatch, see below) during
186 the 1800 ms period after the trial.

187

188 -----

189 Insert Figure 1 here

190 -----

191

192 **Experimental conditions** The experiment comprised 720 trials, run in 16 blocks. Participants
193 were instructed to memorize the tactile/visual samples on the same side, left or right. The task-
194 relevant side (left or right) was randomized per participant for the first block, remained constant
195 for blocks 1-8, and then changed to the opposite side for blocks 9-16. WM load (1, 2 or 3
196 items) varied on a trial-basis independently for each modality, resulting in 9 load conditions
197 with 80 trials each. Memory was unpredictably assessed with a tactile or visual test set,
198 resulting in 40 trials per condition where memory was tested for touch and vision. Training was
199 run before the experiment (depending on individual performance between 40-80 trials).
200 Feedback about the proportion of correct responses was given after each block.

201

202 **Stimulation and randomization procedure.** In each trial, tactile and visual stimuli were
203 simultaneously presented for the bimodal sample set, which was followed by a unimodal test
204 set after 1s. Depending on tactile load (N_T), we separately selected N_T locations for the tactile
205 samples on the left and right side. Tactile tests comprised one stimulus per hand, presented to
206 the same location as a sample, or to a different location (match/mismatch, 50% each).
207 Depending on visual load (N_V), we separately selected N_V locations for the visual samples on
208 the left and right side. These locations were sampled from 110 angular positions (in polar
209 coordinates, left side: 125° to 234° , right side: 305° to 54°), with the constraint that the
210 sampled positions were at least 25° apart. We randomly formed N_V pairs of left- and right-sided
211 positions, and assigned these coordinate pairs to the same concentric ring (N_V rings were
212 selected without replacement to ensure that no ring contained more than 2 stimuli, i.e., 1 per
213 side). Each visual test stimulus matched the location of a sample on half of all trials and
214 appeared at a different location on the other half (30° angular offset relative to the location of a
215 randomly selected sample). Regardless of whether memory was tested for touch or vision,
216 matches/mismatches between sample and test were not correlated for the left and right sides.

217

218 **Acquisition and pre-processing** EEG data, sampled at 500 Hz using a BrainVision amplifier,
219 were DC-recorded from 64 Ag/AgCl active electrodes at standard locations of the extended 10-
220 20 system. Two electrodes at the eyes' outer canthi monitored horizontal eye movements
221 (horizontal electrooculogram, HEOG). Continuous EEG data were referenced to the left
222 mastoid during recording, and re-referenced to the arithmetic mean of both mastoids for data
223 pre-processing. Data were offline submitted to a 20 Hz low-pass filter (Blackman window, filter

224 order 1000). Epochs were extracted for the 1s period after the sample set, and were corrected
225 for a 200 ms pre-stimulus baseline.

226

227 **Artefact rejection and correction** Trials with saccades were rejected using a differential step
228 function that ran on the bipolarized HEOG (step width 200 ms, threshold 30 μV). *Independent*
229 *Component Analysis* (ICA) (Delorme, Sejnowski, & Makeig, 2007) was subsequently used to
230 correct for frontal artefacts such as eye blinks, and residual traces of horizontal eye
231 movements that had not been detected by the step function. We rejected trials in which
232 difference values for corresponding left- minus right-hemispheric electrodes exceeded a fixed
233 threshold of $\pm 50 \mu\text{V}$ (for any electrode pair). We furthermore excluded epochs with unusual
234 spectral profiles; using fast Fourier transforms, we calculated the power of difference values for
235 5 frequency bins (between 1 and 9 Hz) for each trial and electrode pair. Spectral power was
236 normalized across trials by means of z-transforms. An epoch was rejected if z-scores
237 exceeded 3 (for any frequency bin and electrode pair). Notably, this procedure was only used
238 to identify epochs with artefacts; the z-scores were discarded after artefact rejection, and
239 played no role in any statistical analysis. Epochs entered *Fully Automated Statistical*
240 *Thresholding for EEG Artefact Rejection* (FASTER, Nolan, Whelan, & Reilly, 2010) for the
241 interpolation of noisy electrodes, and were subsequently converted to current source densities
242 (CSDs: iterations = 50, m = 4, lambda = 10^{-5} ; Tenke & Kayser, 2012). 93.0% of epochs
243 remained for statistical analysis. Statistical tests were based on correct and incorrect trials; the
244 exclusion of incorrect trials did not change the pattern of results, but would have reduced the
245 signal-to-noise ratio of EEG data.

246

247 **Selection of electrodes and time windows; topographical maps** We separately averaged
248 CSDs across three adjacent electrodes contralateral and ipsilateral to the task-relevant side.
249 As in prior studies (Katus et al., 2017; Katus & Eimer, 2016), the tactile and visual CDA
250 components were measured at lateral central (tCDA: C3/4, FC3/4, CP3/4) and occipital scalp
251 regions (CDA: PO7/8, PO3/4, O1/2). Statistical tests were conducted on difference values of
252 contra- minus ipsilateral CSDs averaged between 300 and 1000 ms after the sample set (cf.
253 Katus et al., 2015a; Vogel & Machizawa, 2004).

254 Spline-interpolated voltage maps illustrate the topographical distribution of lateralized
255 activity during the retention period (300 to 1000 ms). These maps were obtained by subtracting
256 ipsilateral CSDs from contralateral CSDs, with contra-/ ipsilateral referring to the task-relevant
257 side. To collapse data across blocks where the left or right side was task-relevant, electrode
258 coordinates were flipped over the midline for left-side memory blocks. Therefore, in the
259 topographical maps, a negative potential over the left hemisphere indicates the presence of
260 contralateral delay activity for the task-relevant sample stimuli.

261

262 **Statistical analyses** Data were analyzed with paired t-tests and repeated-measures ANOVAs,
263 with Greenhouse-Geisser adjustments when appropriate. Error bars in graphs indicate
264 confidence intervals (CIs) for the true population mean. Thus, error bars that do not overlap
265 with the zero axis ($y \neq 0$) inform about statistically significant tCDA/CDA components; error
266 bars that do not overlap with chance level ($y \neq 50\%$) indicate behavioral performance that is
267 significantly above chance.

268 Bayesian t-tests (Rouder et al., 2009) and the software Jasp (JASP team 2016) were
269 used to calculate Bayes factors for each main effect / interaction in our statistical designs. The

270 Bayes factor denotes the relative evidence for the alternative hypothesis as compared to the
271 null hypothesis, and thus allows for statistical inferences regarding the presence or absence of
272 a modulation. The Bayes factor for the null-hypothesis (BF_{01}) corresponds to the inverse of the
273 Bayes factor for the alternative hypothesis (BF_{10}), and indexes the relative evidence in the data
274 that an effect is absent rather than present. We report the numerically larger BF; reliable
275 evidence for either hypothesis is marked by a $BF > 3$ (Jeffreys, 1961), suggesting that the
276 empirical data is at least 3 times more likely under this hypothesis as compared with the
277 competing hypothesis.

278

279

280 **Results**

281

282 **EEG data.** Tactile and visual CDA components (tCDA/CDA) entered an ANOVA with the
283 factors *Component* (tCDA, CDA), *Tracked modality Load* (TL: tactile load for the tCDA, visual
284 load for the CDA) and *Untracked modality Load* (UL: visual load for the tCDA, tactile load for
285 the CDA). As observed previously (Katus et al., 2017), the CDA component was larger than
286 the tCDA (*Component*: $F(1,29) = 42.893$, $p < 10^{-6}$, $BF_{10} > 10^{32}$). Load manipulations in touch
287 and vision selectively modulated the tCDA and CDA component, respectively (TL: $F(1.344,$
288 $38.973) = 23.238$, $p < 10^{-5}$, $BF_{10} > 10^6$). Critically, the tCDA was not sensitive to differences in
289 visual load and the CDA was unaffected by the manipulation of tactile load (UL: $F(2, 58) =$
290 0.141 , $p = 0.727$, $BF_{01} = 41.251$), and there was no interaction between load in the two
291 modalities (TL x UL: $F(3.001, 87.025) = 0.890$, $p = 0.450$, $BF_{01} = 48.282$). Load-dependent
292 enhancements of CDA/tCDA amplitudes differed between touch and vision (*Component* x TL:

293 $F(2, 58) = 14.457, p < 10^{-5}, BF_{10} > 10^3$). This is illustrated in Figure 2, where the black line
294 graphs on the bottom row show the impact of tactile load on the tCDA (left panel) and the
295 influence of visual load on the CDA (right). Visual load parametrically enhanced the CDA
296 (collapsed for tactile load, comparison 1 vs. 2 visual items: $t(29) = 2.349, p = 0.026, BF_{10} =$
297 2.039 ; 2 vs. 3 visual items: $t(29) = 6.150, p < 10^{-5}, BF_{10} > 10^4$), with largest CDA amplitudes
298 measured in trials with 3 visual items (cf. Vogel & Machizawa, 2004). In contrast, the tCDA
299 reached asymptote for 2 tactile items (collapsed for visual load, 1 vs. 2 tactile items: $t(29) =$
300 $3.712, p < 10^{-3}, BF_{10} = 37.518$; comparison 2 vs. 3 items: $t(29) = 1.215, p = 0.234, BF_{01} =$
301 2.635). All remaining effects were non-significant (*Component* x UL: $F(2, 58) = 0.996, p =$
302 $0.375, BF_{01} = 14.497$; *Component* x TL x UL: $F(4, 116) = 0.955, p = 0.435, BF_{01} = 18.427$).

303

304 -----

305 Insert Figure 2 here

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307

308

309 **Behavioral data** The percentage of correct responses entered an ANOVA with the factors
310 *Tested modality* (touch, vision), *Tested modality Load* (TL: tactile or visual load, depending on
311 whether memory was tested for touch or vision on a given trial) and *Untested modality Load*
312 (UL: load for the other, untested, modality). Participants responded correctly in 79.4% and
313 87.1% of trials where memory was tested for touch and vision, respectively, and this difference
314 was significant (*Tested modality*: $F(1, 29) = 21.583, p < 10^{-4}, BF_{10} > 10^{12}$). Most importantly, as

315 shown in Figure 3A, load manipulations caused strictly modality-specific effects. Performance
316 decreased when load increased in the tested modality from 1 to 2 and 3 items (TL: $F(2, 58) =$
317 $226.533, p < 10^{-20}, BF_{10} > 10^{60}$). Critically, no such decrements were found as a result of
318 increased load in the untested modality (UL: $F(2, 58) = 1.883, p = 0.161, BF_{01} = 26.742$). All
319 other effects were non-significant (TL x UL: $F(4, 116) = 0.812, p = 0.520, BF_{01} = 68.807$;
320 *Tested modality* x TL: $F(2, 58) = 0.880, p = 0.420, BF_{01} = 10.223$; *Tested modality* x UL: $F(2,$
321 $58) = 1.321, p = 0.275, BF_{01} = 16.504$; *Tested modality* x TL x UL: $F(3.081, 89.357) = 1.170, p$
322 $= 0.328, BF_{01} = 17.315$).

323 To assess modality-specific capacity limits for visual and tactile WM in Experiment 1, we
324 calculated Cowan's K (Cowan, 2001) for load-2 and load-4 in vision and touch (collapsing
325 across load in the other untested modality). For visual WM, K values of 1.43 and 1.77 were
326 obtained on load-2 and load-3 trials, and this difference was highly reliable ($t(29) = 7.521, p <$
327 $10^{-7}, BF_{01} > 10^5$). For tactile WM, K values of 1.13 and 1.23 were obtained on load-2 and load-
328 3 trials. This increase was not significant ($t(29) = 1.443, p = 0.160, BF_{01} = 2.022$), suggesting
329 that in contrast to vision, the capacity of tactile WM was already exhausted with a load of 2
330 items. For comparison, K-values increased significantly between load-1 and load-2 trials not
331 only in vision (0.92 versus 1.43; $t(29) = 9.644, p < 10^{-9}, BF_{01} > 10^6$), but also in touch (0.79
332 versus 1.13; $t(29) = 5.838, p < 10^{-5}, BF_{01} > 10^3$).

333

334 -----

335 Insert Figure 3 here

336 -----

337

338 **Experiment 2**

339 In Experiment 1, manipulations of visual and tactile WM load produced entirely
340 modality-specific effects, and no crossmodal interference effects were found either for visual
341 and tactile CDA components or for behavioral performance in the bimodal WM task. This
342 pattern of results seems to suggest that WM capacity limitations are strictly modality-specific.
343 However, alternative interpretations remain. The load manipulations used in Experiment 1 may
344 not have been sufficiently high to produce crossmodal costs. Previous experiments where
345 visual and auditory WM tasks were combined found no dual-task interference when auditory
346 WM load was low (e.g., Morey & Cowan, 2004; Luck & Vogel, 1997), whereas such effects
347 typically emerged with higher loads (e.g. Cocchini et al. 2002; Sauls & Cowan, 2007; but see
348 Fougne et al., 2015, for an exception). Although the WM capacity estimates for vision and
349 touch in Experiment 1 suggest that a maximal load of 3 items exhausted the capacity of visual
350 and tactile stores, performance may have been affected by the specific demands of the
351 lateralized WM task used in this experiment. For example, items that were located on the to-
352 be-ignored side of the sample set could have interfered with the encoding of the task-relevant
353 items in the same modality, resulting in an underestimation of WM capacity limitations.
354 Participants may also have adopted specific strategies for reducing the effective loads of the
355 visual and tactile WM tasks. In the visual task, some perceptual grouping of item locations may
356 have occurred, especially for load-3. On load-3 trials in the tactile task, three of the four
357 stimulators on the task-relevant hand were activated. In some of these trials, participants may
358 have only memorized the single non-stimulated location, thereby reducing tactile load from 3 to
359 1 on these trials.

360 Experiment 2 was designed to address all of these possible shortcomings of Experiment
361 1. In this purely behavioral experiment, bilateral visual and tactile WM tasks were used where
362 participants had to memorize all visual and tactile sample stimuli in both visual hemifields and
363 both hands. Because all sample stimuli were now task-relevant, there was no longer any
364 possibility of interference by to-be-ignored items of the sample set. In bimodal trials, visual and
365 tactile load was varied independently (2 or 4 items). On tactile load-4 trials, two sample items
366 were delivered to the left hand and two to the right hand, so that a strategy to only memorize a
367 single non-stimulated location was no longer available. To eliminate potential grouping
368 strategies for memorized visual positions in trials with high visual load, the spatial WM task
369 was replaced with a color task for the visual modality. We employed the standard color change
370 detection procedure introduced by Vogel & Luck (1997). Observers had to memorize two or
371 four colors and to report whether one of these colors was changed in the test display.
372 Importantly, Experiment 2 also included unimodal baseline trials where two or four visual or
373 tactile items had to be memorized, in order to demonstrate that a unimodal load of 4 items was
374 sufficient to exhaust the capacity of visual and tactile WM stores. If crossmodal interference
375 effects emerge when the effective WM load within both modalities is sufficiently high, such
376 effects should be observed in Experiment 2.

377

378 **Materials and methods**

379

380 **Participants.** 12 participants (average age: 28.8y, 7 female, 10 right-handed) were tested. All
381 were neurologically unimpaired and gave informed written consent.

382

383 **Stimuli and procedure.** These were similar to Experiment 1, with the following exceptions. No
384 EEG was recorded during task performance. The WM task was no longer lateralized, as visual
385 and/or tactile sample stimuli on both sides were task-relevant. WM load was 2 or 4 items
386 (separately varied for touch/vision), and unimodal visual and tactile baseline trials (load 2 or 4)
387 were also included. The tactile task was similar to the one used in Experiment 1. Participants
388 had to memorize the locations of all tactile sample stimuli that could be presented to the index,
389 middle, ring, or little fingers of the left and right hand. The stimulated locations on each hand
390 were chosen randomly and independently on each trial. In load-2 trials, one finger on each
391 hand was stimulated. In load-4 trials, sample stimuli were delivered to two fingers of each
392 hand. The tactile test set included two or four tactile stimuli in load-2 and load-4 trials,
393 respectively. On match trials, the test set was identical to the memory set. On mismatch trials,
394 one randomly selected sample location was replaced by a different location on the same hand.
395 The visual task was now a bilateral color change detection task. Sample displays contained
396 two or four differently colored squares (each covering $0.52^\circ \times 0.52^\circ$ of visual angle). The colors
397 shown on each trial were randomly selected from a set of six possible colors (CIE color
398 coordinates for red: .627/.336; green: .263/.568; blue: .189/.193; yellow: .422/.468; cyan:
399 .212/.350; magenta: .289/.168). All colors were equiluminant (11.8 cd/m^2). On load-2 trials, two
400 sample squares were presented to the left and right of fixation at a horizontal eccentricity of 1° .
401 On load-4 trials, two horizontally aligned squares were presented above and two below
402 fixation, each at a horizontal and vertical eccentricity of 1° . Participants had to memorize the
403 colors of all sample stimuli. On match trials, the test set was identical to the sample set. On
404 mismatch trials, one item in the test set changed its color relative to the sample set.

405 The experiment included 480 trials, run in 8 blocks of 60 trials. There were 320 bimodal
406 and 160 unimodal trials that were randomly intermixed in each block. For bimodal trials, visual
407 and tactile load (2 or 4 item) was varied independently, resulting in four different load
408 conditions. Memory was unpredictably tested for touch or vision (160 trials each, with 40 trials
409 for each for the four load conditions). In the unimodal trials, the sample and test sets were
410 presented in the same modality (80 tactile and 80 visual; with 40 trials each for load-2 and
411 load-4). As in Experiment 1, vocal responses (“a” for match and “e” for mismatch) were
412 registered with a headset microphone for each trial. The timing of all sample and test events
413 was identical to Experiment 1.

414

415

416 **Results**

417 Figure 3B shows accuracy on trials where touch or vision was tested, for each
418 combination of WM load in the tested modality (2 or 4 items) and load in the untested modality
419 (0 items in the unimodal baseline, otherwise 2 or 4 items). There were clear effects of
420 increasing WM load for the tested modality, but no apparent effects of load in the other
421 untested modality. We first assessed whether increasing visual and tactile load to 4 items was
422 sufficient to exhaust the capacity of visual and tactile WM by calculating Cowan’s K as a
423 measure of WM capacity for the two single-task visual and tactile baseline conditions,
424 separately for loads of 2 and 4 items. With load-2, K was 1.91 and 1.94 for the tactile and
425 visual tasks, respectively, reflecting near-perfect performance. With load-4, K was 3.13 in the
426 tactile task and 3.25 in the visual task. This indicates that a WM load of 4 items exhausted the
427 capacity of both tactile and visual stores.

428 For the main analysis, accuracy entered an ANOVA with the factors *Tested modality*
429 *Load* (TL: 2 or 4 items), *Untested modality Load* (UL: 0, 2 or 4 items) and *Tested Modality* (TM:
430 vision or touch). This analysis confirmed the presence of strong modality-specific load effects
431 in the absence of any crossmodal effects. Accuracy was lower when 4 rather than 2 items had
432 to be memorized in the tested modality (TL, $F(1,11) = 43.575$, $p < 10^{-4}$, $BF_{10} > 10^{15}$). In
433 contrast, there was no impairment of WM performance due to load in the untested modality
434 (UL: $F(2, 22) = 1.333$, $p = 0.284$, $BF_{01} = 6.550$), and no interaction between load in the tested
435 and untested modalities (TL x UL: $F(2, 22) = 0.623$, $p = 0.546$, $BF_{01} = 7.339$).¹ Accuracy did
436 not differ between the tactile and visual tasks (93.4% vs. 94.5%, averaged across all load
437 conditions, main effect TM: $F(1, 11) = 0.631$, $p = 0.444$, $BF_{01} = 2.220$). There were no other
438 significant interactions (TM x TL: $F(1, 11) = 0.095$, $p = 0.763$, $BF_{01} = 3.634$; TM x UL: $F(2, 22) =$
439 0.677 , $p = 0.518$, $BF_{01} = 7.553$; TM x TL x UL: $F(2, 22) = 0.648$, $p = 0.533$, $BF_{01} = 4.682$).

440

441

¹ To assess whether behavioral measures reflected a tradeoff between the number of tactile and visual items maintained in WM, we calculated ΔK to obtain a normalized measure of any interference between the tactile and visual tasks. The ΔK measure (Fougnie & Marois, 2011) quantifies dual-task interference relative to single-task baseline conditions in terms of a value ranging between 0% (reflecting fully independent WM capacities for two tasks/modalities) and 50% (fully shared WM capacity). ΔK for trials where load was 4 in both modalities was on average 0.4% (relative to the unimodal 4-item baselines). ΔK values were significantly below 50% ($t(11) = 12.530$, $p < 10^{-7}$, $BF_{10} > 10^4$), but not different from 0% ($t(11) = 0.112$, $p = 0.913$, $BF_{01} = 3.461$), indicating distinct rather than shared capacities for tactile and visual WM.

442 Discussion

443

444 We investigated whether the maintenance of information in WM is mediated by a domain-
445 general (i.e., central/supramodal) mechanism or by processes that operate independently for
446 WM content that has been encoded via different sensory modalities. In two experiments, we
447 employed bimodal tactile-visual WM tasks, and manipulated WM load orthogonally for both
448 modalities. In Experiment 1, spatial WM tasks were used in both modalities. EEG was
449 recorded during task performance, and tactile and visual CDA components (tCDA/CDA) were
450 measured to concurrently track the activation of tactile and visual WM representations.

451 If visual and tactile WM representations were maintained by a central mechanism,
452 varying visual load should affect the somatosensory tCDA component, and changes in tactile
453 load should modulate the visual CDA. There were no such crossmodal load effects in
454 Experiment 1. CDA amplitudes were entirely unaffected by manipulations of tactile WM load,
455 and tCDA amplitudes remained equally insensitive to manipulations of visual load. The
456 reliability of these null-effects was confirmed by Bayesian statistics. Bayes factors (BFs, see
457 Rouder et al., 2017) for each main effect and interaction in our factorial design (such as TL,
458 UL, and TL x UL) quantify the relative evidence in the data for the null hypothesis (e.g., the
459 absence of an effect of WM load in the untracked modality) as compared to the alternative
460 hypothesis (the presence of such an effect). The BFs strongly support the null hypothesis with
461 regards to load in the untracked modality (factor UL) and its interaction with load in the tracked
462 modality (TL x UL), thus confirming the absence of crossmodal interference effects on the
463 tCDA (due to visual load), and on the visual CDA (due to tactile load). Adopting a commonly
464 used categorization of BF sizes (Jeffreys, 1961), we found *very strong* evidence for the

465 absence of tCDA/CDA modulations due to the factor UL ($BF_{01} = 41$), as well as *very strong*
466 evidence for the absence of an interaction between TL and UL ($BF_{01} = 48$). For both these
467 effects, the null hypothesis was over 40 times more likely to account for the empirical data than
468 the alternative hypothesis. This electrophysiological evidence for the absence of crossmodal
469 load effects is at least 4 times stronger than suggested by behavioral evidence, obtained in a
470 recent auditory/visual WM experiment (Fougnie et al., 2015), where BF_{S01} ranged between 7
471 and 10. It is notable that these highly reliable null-effects were accompanied by *decisive*
472 evidence for an impact of factor TL ($BF_{10} > 10^6$), indicating the presence of load-dependent
473 tCDA/CDA modulations for manipulations of tactile/visual WM load, respectively. These results
474 therefore unequivocally support the conclusion that the tactile and visual CDA components
475 reflect WM maintenance processes that operate in a strictly modality-specific fashion.

476 This conclusion was further supported by the behavioral results of Experiment 1. For the
477 modality assessed at memory test, increments in WM load led to parametric reductions in
478 performance, but performance was insensitive to load in the untested modality (Fig. 3A).
479 Converging with electrophysiological data, Bayesian analysis of behavioral performance
480 provided *strong* to *very strong* evidence for the absence of crossmodal load effects ($BF_{01} = 27$
481 for factor UL and $BF_{01} = 69$ for the TL x UL interaction), and *decisive* evidence for the
482 presence of modulations due to increments in load for the modality that was tested after the
483 trial ($BF_{10} > 10^{60}$ for factor TL). It would in principle have been possible to observe crossmodal
484 load effects for performance only, without any corresponding effects on CDA and tCDA
485 components. Such a pattern of results would have suggested that crossmodal interference
486 specifically affects stages other than WM maintenance, such as the comparison between
487 memorized and test stimuli. In fact, the electrophysiological and behavioral results of

488 Experiment 1 mirrored each other perfectly, with no evidence for crossmodal load effects for
489 either measure. This indicates that none of the stages involved in WM performance were
490 selectively affected by concurrent WM load in another modality.

491 The fact that performance in Experiment 1 was better in the visual relative to the tactile
492 task could indicate that participants had prioritized vision over touch. This should have
493 produced asymmetrical crossmodal interference effects according to a domain-general
494 account of WM capacity. For example, if visual stimuli had been preferentially encoded into a
495 shared domain-general WM store, performance on trials where memory was tested for a tactile
496 load of 3 items should be worse with visual load-3 relative to visual load-1. Because accuracy
497 data from trials where vision or touch were tested were analyzed together, the presence of
498 selective crossmodal costs for the low-priority (tactile) modality should have been reflected by
499 a three-way interaction (Tested modality x TL x UL). As reported above, there was strong
500 evidence for the absence of this interaction ($BF_{01} > 17$). Likewise, we found strong evidence
501 against asymmetrical crossmodal interference effects on tactile and visual CDA components
502 (Component x TL x UL; $BF_{01} > 18$). These observations suggest that performance differences
503 between the tactile and visual tasks in Experiment 1 were not attributable to a modality
504 prioritization strategy.

505 The ERP results of Experiment 1 revealed a difference between the effects of memory
506 load in the tracked modality (TL) on CDA and tCDA components. Increasing visual load led to
507 parametric amplitude enhancements of the CDA component over visual cortex, with largest
508 CDA amplitudes on trials where 3 visual items had to be memorized, in line with previous
509 experiments of unimodal visual WM (McCollough et al., 2007; Vogel & Machizawa, 2004). The
510 tactile CDA (tCDA) component over somatosensory cortex increased in amplitude when tactile

511 load increased from 1 to 2 items (compare Katus et al., 2015a for unimodal tactile WM), but no
512 further tCDA enhancement was obtained for 3 tactile items. This difference between the visual
513 and tactile CDA components was mirrored by behavioral capacity estimates for visual and
514 tactile WM. In vision, Cowan's K increased significantly when visual load was increased from 2
515 to 3 items, whereas no such increase was observed for touch, indicating that in the specific
516 task context of Experiment 1, the capacity limit of tactile WM was already reached with 2 items.
517 The fact that tactile WM capacity was substantially higher in the non-lateralized WM task used
518 in Experiment 2 shows that more than 2 tactile items can be successfully maintained in some
519 conditions (see below for further discussion). It remains to be determined whether it is
520 principally possible to obtain tCDA enhancements beyond a load of 2 tactile items in other task
521 contexts. Importantly, any difference between CDA and tCDA asymptotes does not affect our
522 key finding that the load-dependent modulations of CDA and tCDA amplitudes were strictly
523 modality-specific, as demonstrated by the fact that these amplitudes remained entirely
524 unaffected by manipulations of WM load in the other modality.

525 To rule out the possibility that the absence of crossmodal load effects was due to the
526 specific task demands of Experiment 1, we ran a second behavioral experiment with a non-
527 lateralized design where all sample stimuli were task-relevant. Visual and tactile load was 2 or
528 4 items, the spatial WM task in the visual modality was replaced by a color change detection
529 task, and unimodal baseline trials were included. The results of Experiment 2 fully confirmed
530 the findings of Experiment 1, with strictly modality-specific load effects, and no evidence for
531 any crossmodal interference. Capacity estimates on baseline trials confirmed that a load of 4
532 items was sufficient to exhaust the capacity of visual and tactile stores. Furthermore, the
533 design of Experiment 2 prevented participants from reducing effective WM load by grouping

534 locations in the visual task, or remembering non-stimulated locations in the tactile task. The
535 fact that load effects remained entirely modality-specific in this experiment thus suggests that
536 the analogous pattern observed in Experiment 1 was not due to insufficient demands on
537 storage capacity, but instead reflects the independence of WM maintenance processes in
538 different modalities.

539 It is notable that WM performance differed considerably between these two
540 experiments, with much better performance in Experiment 2. This difference was particularly
541 pronounced for the tactile WM task, in spite of the fact that participants had to memorize
542 stimulated locations in both experiments. Even on tactile load-1 trials, accuracy was well below
543 100% in Experiment 1. The improved tactile WM performance in Experiment 2 is most likely
544 due to the fact that a non-lateralized WM task was used where all tactile sample stimuli on
545 both hands to be memorized. In contrast to the lateralized task in Experiment 1, there was no
546 longer any interference from stimulated locations on the other unattended hand, and the
547 average distance between two tactile stimuli on the same hand was larger. The finding that
548 approximately three tactile stimuli could be successfully retained on load-4 trials in Experiment
549 2 demonstrates that under such optimal conditions, the capacity of tactile WM stores appears
550 to be limited to three items. Visual WM accuracy was also better with the highly distinguishable
551 color stimuli used in Experiment 2 relative to the spatial WM task with monochrome stimuli in
552 Experiment 1. Previous research has shown that visual WM performance is affected by the
553 features that have to be memorized, with tasks involving color typically yielding better
554 performance than tasks where other stimulus dimensions have to be retained (e.g., orientation
555 or shape; Awh et al. 2007; Alvarez & Cavanagh, 2004; Woodman & Vogel, 2008). In addition,
556 some interference from stimuli in the unattended visual field may also have contributed to the

557 lower visual WM performance in Experiment 1. However, the behavioral estimate of WM
558 capacity in Experiment 2 ($K = 3.25$ items) is in line with the parametric load-dependent CDA
559 enhancements observed in Experiment 1 (for up to 3 visual items).

560 What does the absence of crossmodal interference effects on performance in both
561 experiments, and on CDA and tCDA amplitudes in Experiment 1, imply for the nature of
562 mechanisms that control the storage of information in WM? It is established that WM and
563 selective attention are closely intertwined (Awh & Jonides, 2001; Gazzaley & Nobre, 2012;
564 Ruchkin, Grafman, Cameron, & Berndt, 2003), and that attentional mechanisms underpin the
565 active maintenance of WM representations (e.g., Awh, Vogel, & Oh, 2006; Emrich, Lockhart, &
566 Al-Aidroos, 2017). Attention optimizes WM representations in a goal-directed fashion (Lepsien
567 & Nobre, 2006; Myers, Stokes, & Nobre, 2017), and the allocation of attention to task-relevant
568 items in WM enhances performance (e.g., Griffin & Nobre, 2003). In line with these ideas,
569 electrophysiological evidence suggests that lateralized delay activity (such as the tCDA/CDA)
570 does not reflect information storage as such, but more specifically the attentional activation of
571 representations of memorized stimuli in sensory cortex (e.g., Berggren & Eimer, 2016; Katus
572 & Eimer, 2015; Kuo, Stokes, & Nobre, 2012). This is analogous to the early interpretation of
573 delay activity in the prefrontal cortex of monkeys as the indication of a top-down attentive
574 process (Fuster & Alexander, 1971). While passive mechanisms may also be involved in the
575 short-term storage of information (Mongillo, Barak, & Tsodyks, 2008; for a review of “activity-
576 silent WM”, see Stokes, 2015), CDA/tCDA components reflect activation-related aspects of
577 WM maintenance that are mediated by selective attention (Unsworth, Fukuda, Awh, & Vogel,
578 2015; Vogel, McCollough, & Machizawa, 2005; Katus & Eimer, 2015; Katus & Müller, 2016). If
579 these active maintenance processes were limited by the capacity of a central attention

580 mechanism (Cowan, 2011), they should be adversely affected by increasing WM load in
581 another modality, provided that this results in an overall bimodal WM load exceeds the
582 capacity of this domain-general mechanism. However, the present study found that increasing
583 multisensory load above the 3-4 item capacity limit of unimodal WM (Cowan, 2001; Vogel
584 & Machizawa, 2004) did not produce any crossmodal interference effects for CDA and tCDA
585 amplitudes. The absence of such effects suggests that the maintenance processes indexed by
586 the tCDA/CDA components are mediated by modality-specific attention mechanisms with
587 independent capacities for tactile and visual information that are activated in parallel during the
588 maintenance of multisensory information.

589 Such modality-specific attentional control processes operate within hierarchically
590 organized WM systems (Brady, Konkle, & Alvarez, 2011), which are controlled in a top-down
591 fashion by higher-level executive mechanisms (e.g., Katus et al., 2017). This distributed nature
592 of WM (Christophel, Klink, Spitzer, Roelfsema, & Haynes, 2017; Fuster, 2009) can account for
593 the fact that the capacity of multisensory WM (i.e., the number of multisensory items that can
594 be recalled at memory test) exceeds the capacity of unimodal WM (Cowan et al., 2014;
595 Fougne et al., 2015; Fougne & Marois, 2011). In such a distributed processes architecture,
596 capacity limitations can arise due to the competition between stimulus representations that are
597 stored in the same cortical map (in somatosensory vs. retinotopic cortex, for tactile vs. visual
598 information; cf. “cortical real estate” hypothesis: Bergmann et al., 2016; Franconeri, Alvarez, &
599 Cavanagh, 2013), and due to capacity limitations of the maintenance processes that keep
600 these sensory representations in an active state (as indexed by the tCDA/CDA in tactile/visual
601 WM tasks). Instead of assuming that multisensory items compete for representation in a
602 central WM store, and/or for domain-unspecific attention resources (Cowan, 2011; Saults

603 & Cowan, 2007), crossmodal interference effects observed in bimodal WM tasks are likely to
604 reflect factors that are unrelated to WM capacity (e.g., costs that arise during dual-task
605 coordination, or during the simultaneous encoding of multisensory stimuli, response selection,
606 etc.: Brisson & Jolicoeur, 2007; Cocchini et al., 2002; Fougny et al., 2015 for further
607 discussion). Competitive interactions between modality-specific maintenance processes may
608 also contribute to such costs, given that these processes rely on feedback signals from a
609 common source (such as a central executive; Baddeley, 2003). This is most likely to happen in
610 bimodal WM tasks with extremely high load (e.g., 10 multisensory items, as in Cowan et al.,
611 2014), as such tasks may compromise the ability of the central executive system to effectively
612 coordinate and sustain concurrent activation processes within different sensory modalities (cf.
613 Tamber-Rosenau & Marois, 2016).

614

615 **Conclusion** Building on evidence that WM recruits sensory mechanisms for information
616 storage, we here show that WM additionally recruits modality-specific control mechanisms to
617 regulate the activation of stimulus representations in somatosensory and visual cortex. The
618 parallel functioning of such distributed processes during the retention of multisensory
619 information explains the absence of crossmodal load effects on behavioral and
620 electrophysiological measures of WM, and can also account for the enhanced capacity of
621 multisensory WM relative to unimodal WM.

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633

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774 **Figure legends**

775 **Figure 1. Multisensory memory task for locations in Experiment 1.** Simultaneously
776 presented tactile and visual sample sets (duration 200 ms) were followed by a unimodal –
777 tactile or visual – test set after 1 second. Participants memorized the locations of the tactile
778 and visual samples on the same side (left or right, varied block-wise) and judged whether any
779 of these memorized locations matched with the memory test (50% match/mismatch, separately
780 randomized for the attended/ignored sides). WM load (1, 2 or 3 items) alternated unpredictably
781 across trials, and independently for the tactile and visual sample sets. The graph delineates a
782 trial with visual load-3 and tactile load-2. The dots on the monitor represent the locations of the
783 visual stimuli, and dots on the hands indicate the fingers that received tactile samples.

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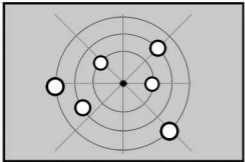
785 **Figure 2. EEG data in Experiment 1. (A)** Separate rows display tCDA difference waves,
786 measured over somatosensory cortical regions, during the retention delay of tactile load-1,
787 load-2 and load-3 trials. Line color indicates WM load in the visual modality (blue, yellow and
788 red, for 1, 2 or 3 visual items). Statistical analyses were performed on the average of tCDA

789 amplitudes between 300 and 1000 ms, which are displayed for all tactile/visual load
790 combinations in the bottom right panel. The left panel and the topographies show the impact of
791 tactile load on data that were collapsed across the visual load conditions. **(B)** CDA difference
792 waves, measured over visual cortical regions, as a function of visual load (separate rows) and
793 tactile load (different colors). Mean CDA amplitudes for all tactile/visual load combinations are
794 displayed in the fourth row, right panel. The left panel and the topographies illustrate CDA
795 amplitudes, collapsed across the tactile load conditions. Note the different scales for the
796 tCDA/CDA in (A) and (B); negative is plotted downwards.

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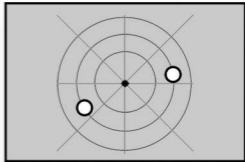
798 **Figure 3. Behavioral results in Experiment 1 (A) and Experiment 2 (B).** Performance (%
799 correct) in trials where memory was tested for touch, for vision, and collapsed across both
800 modalities, is plotted against WM load in the untested modality. In both experiments,
801 performance decreased only when load increased for the tested modality (compare the
802 different line types), but not for load increments in the untested modality (x-axis).

803



Samples Vision and Touch

50%
↗



50%
↘
Test Vision or Touch

