1 Division of labour is biased towards equality amongst 2 collaborators in a dyadic short-term memory task

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39 **Abstract**

40

41 Human workers often divide labour on the basis of individual qualities. However, contemporary
42 work on decision-making suggests collaborators value opinions equally, even when they are
43 unequally skilled. We investigated whether this equality bias extends to division of labour in a
44 collaborative game that leverages inter-individual short-term memory capacity differences. Pairs
45 were shown eight memorisable items to divide among themselves, only communicating through
46 their computer screens that displayed who claimed which items. After this, participants recalled
47 randomly selected claimed items. To incentivise collaboration, pairs were rewarded for their
48 combined recall accuracy. Although we hypothesised they would maximise reward by dividing
49 items according to each individual's capacity, pairs divided the number of to-be-remembered items
50 equally. Furthermore, individuals' collaboration ratings were unaffected by capacity or
51 performance, but instead negatively correlated with task-irrelevant variability in claimed item
52 locations. Finally, differences in claimed item numbers correlated with inter-individual differences
53 in conscientiousness and social apathy. Our findings suggest humans have an equality bias when
54 dividing labour between collaborators, even if they are of unequal skill.

55

56 **Keywords:** social cognition; collaboration; apathy; motivation; visual short-term memory;
57 behavioural volatility; optimal behaviour

58

59 Introduction

60

61 In joint cognitive tasks, pairs or groups of individuals collaborate to achieve a common goal.
62 This could be to find a particular target among distractors, to make perceptual decisions, or to recall
63 particular stimulus features. Interestingly, verbal communication is not a pre-requisite for successful
64 collaboration in these tasks. This is illustrated in a study where pairs of collaborating individuals
65 (also known as “*dyads*”) were asked to jointly search for a particular target (Brennan, Chen,
66 Dickinson, Neider, & Zelinsky, 2008). The individuals, each in a separate room, were presented
67 with the same field of distractor stimuli (“Q”) among which a target (“O”) could be embedded. In
68 one condition, the only information shared between the pair was where each individual was
69 currently looking, which was recorded by an eye tracker, and displayed on the other’s display.
70 Collaborative search proved to be faster than the solitary equivalent.

71 One important observation in the aforementioned study was that pairs implicitly divided the
72 search space in two halves, with each taking responsibility for their own half (Brennan et al., 2008).
73 In a condition in which pairs were allowed to speak, pairs verbally decided on a highly similar
74 strategy, although being allowed to communicate in this way did not seem to improve performance
75 (Brennan et al., 2008). This finding has since been replicated (Neider, Chen, Dickinson, Brennan, &
76 Zelinsky, 2010). In addition, the collaborative benefit seems to correlate with the similarity of
77 individuals’ verbal communication style, and their social proximity (Brennan & Enns, 2015).
78 Furthermore, the benefit of knowing about collaborators’ actions extends across perceptual
79 domains, for example when this information is auditory or even vibro-tactile (Wahn et al., 2016).

80 Modelling work suggests that joint visual search with real-time communication is quicker
81 because of active collaboration (Brennan & Enns, 2015), but not when participants simply follow
82 each other’s gaze around the search array (Messmer, Leggett, Prince, & McCarley, 2017; Yamani,

83 Neider, Kramer, & McCarley, 2017). The latter behaviour occurs more in competitive joint search,
84 whereas collaborative search facilitates participants to more efficiently divide the search space
85 (Niehorster, Cornelissen, Holmqvist, & Hooge, 2019). When joint visual search is performed
86 without direct feedback, collective search is also faster than independent search, albeit to a lesser
87 extent: When feedback is given only after a trial, performance is better for groups of two or three
88 compared to single participants, and is correlated with individual search speed (Wahn, Czeszumski,
89 & König, 2018). This suggests that without real-time feedback, a collective benefit can be achieved
90 through statistical facilitation rather than collaboration. However, real-time information on
91 collaborators improves performance to a greater extent. In the literature, these concepts are referred
92 to as “collective benefit” and “collaborative benefit” (Wahn, Kingstone, & König, 2018).

93 Behavioural adaptation to group performance

94 Although the cognitive tasks described above require individuals to coordinate or respond to
95 each other’s actions, they do not require individuals to be aware of each other’s level of cognitive
96 skill. By contrast, real-life collaborations often require a division of labour that is in keeping with
97 individual capacity. For example, when lifting wooden planks of increasing length, pairs of
98 participants decide to start jointly carrying planks at a length that was proportional to the pair’s
99 mean arm span (Richardson, Marsh, & Baron, 2007; Sebanz, Bekkering, & Knoblich, 2006). This
100 illustrates that pairs were not only aware of each other’s capacity to carry planks, but also able to act
101 on this knowledge.

102 Recent work on joint perceptual decision-making has demonstrated that individuals within a
103 pair assume their collaborator is equally capable, and that violations of this assumption are
104 detrimental to joint performance (Mahmoodi et al., 2015). In this study, participants had to first
105 individually decide on whether a target appeared in a first or second interval, and in the case of
106 disagreement one was randomly chosen to be arbitrator and make a final decision. Crucially, each

10

107 individual provided a confidence rating, which the arbitrator could use to make their decision.
108 Arbitrators were shown to weigh each response equally, even when differences in task performance
109 were introduced between the participants by making one individual's task harder, and when
110 participants received a group reward (Mahmoodi et al., 2015). This elegantly suggests that humans
111 weigh their collaborators' opinions equally rather than optimally.

112 Unfortunately, perhaps in a small-scale application of the Dunning-Kruger effect (Kruger &
113 Dunning, 1999), less skilled individuals were more likely to report higher confidence in wrong
114 decisions (Mahmoodi et al., 2015). This is an inherent problem with self-report, and potentially
115 clouded arbitrators' ability to make a skill-based decision in trials with disagreement. In addition,
116 individual participants could not directly affect the performance of the other participant. Hence, it
117 remains unclear whether humans would act on the perceived cognitive skills of collaborators when
118 they are given a chance to do so.

119 Joint visual short-term memory

120 Here, we present a novel collaborative task that requires a pair of participants to briefly
121 remember a number of visual stimuli. In one variety of visual short-term memory tasks (Zhang &
122 Luck, 2008), participants are presented with a memory array of several items, for example coloured
123 squares or bars with a particular orientation. They are then required to maintain the items in
124 memory for a duration of several seconds. After this delay, one item is probed, and participants are
125 required to reproduce the original colour or orientation.

126 The advantage of using such a task to investigate collaborative behaviour, is that visual
127 short-term memory is a well-studied system (Baddeley & Hitch, 1974; Brady, Konkle, & Alvarez,
128 2011; Luck & Vogel, 2013; Ma, Husain, & Bays, 2014). Although there is debate on the precise
129 architecture, researchers agree that short-term memory is of a limited capacity (Adam, Vogel, &
130 Awh, 2017; Alvarez & Cavanagh, 2004; Awh, Barton, & Vogel, 2007; Baddeley & Hitch, 1974;

131 Bays, 2015; Bays & Husain, 2008; Cowan, 2001; Wilken & Ma, 2004). In addition, visual short-
132 term memory capacity can be measured reliably within individuals, and shows a wide variability
133 between individuals (Luck & Vogel, 2013).

134 It is important to note that visual short-term memory is closely related to visual attention,
135 and in fact that active maintenance requires attention (Zokaei, Heider, & Husain, 2014). Our
136 approach is thus quite closely aligned with aforementioned joint cognition studies, and rather
137 different from joint long-term memory studies that usually test joint recall of individually studied
138 items, or joint encoding and recall after a longer period of time (Rajaram & Pereira-Pasarin, 2010).

139 In our task, individuals receive objective feedback on their own and their partner's
140 performance. Performance is translated into a group reward in a non-linear way that punishes larger
141 errors more strongly than smaller errors. Crucially, participants can claim stimuli for themselves by
142 looking at them, and are later probed only on stimuli that they have claimed. This means that
143 participants can choose to take responsibility for more or fewer stimuli. In line with aforementioned
144 research on physical collaboration (Richardson et al., 2007; Sebanz et al., 2006), we hypothesised
145 that participants would learn how well they were doing compared to their partner, and adjust their
146 behaviour accordingly.

147 For example, if a pair of participants is asked to remember a total of eight items, one
148 participant could notice they were doing markedly better than their partner when each claim four
149 items. On the next trial, they could choose to claim one additional item, which would increase their
150 memory load to five items. As a consequence, their partner's memory load would be reduced to
151 three items. Although their own performance would decrease slightly, their partner's performance
152 could increase by a greater amount, and their joint reward would be greater.

153 In addition, we hypothesised that participants would judge the collaboration to be better
154 when their partner was more sensitive to the difference in cognitive ability between them. In other

155 words, we expected pairs that had a larger discrepancy in visual short-term memory capacity to rate
156 their collaboration as better if the higher-capacity individual adjusted their behaviour to help the
157 lower-capacity individual.

158 Finally, we decided to measure social apathy (Ang, Lockwood, Apps, Muhammed, &
159 Husain, 2017). Taking on more items in a collaborative task could be viewed as pro-social, and thus
160 could be mediated by social apathy (Lockwood et al., 2017). Reasoning along these lines, one could
161 hypothesise that higher levels of social apathy would correlate with lower levels of behavioural
162 change inspired by inter-collaborator differences in ability. To avoid overlooking potential overlap
163 between apathy as a personality trait and more traditional personality traits, we also measured the
164 typical Big Five (O'Connor, 2002).

165

166

167 **Methods**

168

169 **Procedure**

170 After expressing interest, potential participants were approached via email to schedule a
171 testing session. They were also requested to complete an online questionnaire in advance, which
172 included questions on demographic data, Big-Five personality domains (Gosling, Rentfrow, &
173 Swann, 2003), and apathy in the behavioural, social, and emotional domain (Ang et al., 2017).
174 Informed consent to completing the questionnaire was acquired at the start of the online session.
175 Informed consent to participation in the testing session was acquired in written form before the start
176 of the session.

177 Testing sessions took place in Lund University’s ‘Digital Classroom’, which contains 25
178 computers with eye trackers (SMI RED-m at the time of testing) that are connected to the same
179 network, and can share data in real-time. For details, see (Nyström, Niehorster, Cornelissen, &
180 Garde, 2017). Participants were each assigned a cardboard cubicle that contained a desk with a
181 computer and an eye tracker (**Figure 1**). All computers were connected to the same network, and
182 controlled from a master computer.

183

184

Figure 1 – Lund University’s Digital Classroom setup. A total of 25 computers with SMI RED-m eye trackers and a master computer are connected through the same network. Here, we used up to 10 of the computers to run experiments on, and white cardboard cubicles to hide participants from each other’s view.

185

186 During a testing session, participants first completed an individual visual short-term memory
187 assessment (described below). When all participants finished, their eye trackers were calibrated.
188 After calibration, participants performed a collaborative task (described below) with randomly
189 assigned partners. Participants were unaware of who their partner was, as they were not identified
190 within the game. Because participants were inside a cubicle that blocked others from view, and
191 were instructed to remain silent throughout the game, there were no external cues through which
192 partners could be identified.

193 We aimed to run three consecutive collaborative tasks per testing session, with new pairings
194 on every run. We succeeded in this aim in all but one session, in which we did not have time for a
195 third collaborative task run (consenting and calibrating 10 participants took longer than anticipated).
196 Testing sessions did not last longer than 1 hour.

197

198 Participants

199 Participants were recruited through advertisement on informal channels at Lund University,
200 including physical and digital notice boards. In addition, we advertised with the Lund International
201 Society of Psychology (LISP) by offering a free MSc-level lecture on the applications of eye
202 tracking in psychological research (attendants were encouraged but not mandated to participate). In
203 total, 41 individuals expressed interest and completed our pre-participation questionnaires. Out of
204 those, 3 individuals took part in a pilot, and 32 individuals in a testing session. This number
205 includes two authors, who each participated once, in sessions where an odd number of participants
206 showed up. Participants were compensated for their time with gift cards that were valid in a variety
207 of local shops.

208 A total of seven sessions were run. The first (N=3) was a pilot session to test whether the
209 setup worked as expected, and did not yield usable data. The following six sessions (N=9 + author
210 Niehorster, N=4, N=2, N=4, N=4, N=3 + author Dalmaijer) ran smoothly, with the exception of the
211 malfunction of one computer that interrupted two pairs in the first session. In addition, we had to
212 exclude one session where anonymisation was compromised due to only two of the scheduled
213 participants showing up.

214 The testing sessions yielded usable data from 32 unique pairs of individuals. These
215 individuals (N=26, 7 males, 19 females) had a mean age of 25.7 years with a standard deviation of
216 4.1 and a range of 21-38 years, varied in highest completed education from high school to doctorate

217 (2 high school, 14 Bachelor, 7 Master, 3 Doctorate), and had a variety of nationalities (Bulgaria,
218 Germany, Hungary, Iceland, India, Italy, Mexico, Netherlands, Russia, Sweden, Thailand, Turkey,
219 USA).

220

221 Individual visual short-term memory capacity assessment

222 The individual short-term memory assessment aimed to test participants' capacity to recall
223 and reproduce visual information (**Figure 2**). It consisted of 80 trials, during each of which 2 or 4
224 items with a unique orientation were presented for 5 seconds. This was followed by a maintenance
225 period of 3 seconds during which the items were masked. The maintenance period ended with the
226 appearance of the mouse cursor, and a circle around one of the (still masked) items. Participants
227 could then use the computer mouse to precisely indicate the orientation of the probed item as they
228 remembered it. On the first click, the mask was replaced by an item that was oriented toward the
229 current mouse position. Participants could hold down the mouse button while moving the cursor to
230 rotate the item to the remembered orientation, and press the space key to confirm.

231 The items were sinusoidal gratings with a diameter of 1.5 degrees of visual angle, and a
232 spatial frequency of five cycles per stimulus. Each item had a unique and randomly generated
233 orientation that differed from the other items by at least ten degrees. Item locations were also
234 randomly generated on each trial, were separated by at least 3.35 degrees of visual angle, and
235 avoided areas near the screen edge (left/right borders were defined as 10% of the screen width, and
236 top/down as 10% of the screen height). Masks were noise patches with the same diameter as the
237 gratings. Each trial was preceded by a centrally presented fixation cross, which was visible for a
238 randomly selected interval between 1 and 1.5 seconds.

239

240

Figure 2 – Experimental procedure in two visual short-term memory tasks. In these tasks, participants see a number of items for a limited amount of time, then hold them in memory for three seconds, after which one of the items is probed. The orientation of the probed item can be adjusted by participants, who are asked to reproduce the memorised orientation. The individual assessment was designed to estimate individual participants' visual short-term memory capacity. The collaborative game was designed to allow participants to divide memory items between them in any way they preferred. Participants received direct visual feedback on what items they and their collaborator claimed.

241

242 We computed errors as the circular distance between a participant's responses and the

243 original orientation of items (i.e. the difference in angle between a probed item and the associated

24
 244 response). For each participant, we established an error distribution for both the two-item and the
 245 four-item condition (40 trials each). These error distributions were fitted (using a maximum-
 246 likelihood procedure) to a mixture model (**Equation 1**) that described the probability density
 247 function of responses, and estimated the proportion of trials in which an item was forgotten β
 248 (guesses), the proportion of trials in which the response to one item was made with another item in
 249 mind γ (“swap errors”), and the precision of recall σ that was defined as the converted spread
 250 parameter (analogous to a normal distributions standard deviation) of a Von Mises distribution
 251 (Bays, Catalao, & Husain, 2009).

252

$$253 \quad p(\hat{\theta}) = (1 - \gamma - \beta) \phi_{\sigma}(\hat{\theta} - \theta) + \gamma \frac{1}{2\pi} + \beta \phi_{\sigma}(\hat{\theta} - \theta^*) \quad (1)$$

254 *Where:*

255 - $\hat{\theta}$ are a participant’s responses on each trial in either the 2-item or 4-item condition

256 - θ are the orientations of the probed item on each trial

257 - θ^* are the orientations of the non-probed items on each trial

258

259 After establishing the proportion of trials in which participants did not guess, and the
 260 precision of their recall in those trials, we could estimate their visual short-term memory capacity κ
 261 (**Equation 2**). Specifically, we computed the Kullback-Leibler divergence (Kullback & Leibler,
 262 1951) between the probability density function that fitted their non-guessed responses best
 263 (**Equation 3**), and the probability density function that describes pure guessing (**Equation 4**). This
 264 metric quantifies the information gain when a participant remembers an item instead of randomly
 265 guessing its orientation. An approximation of visual short-term memory capacity κ (in *bits*) can be

26
266 computed by multiplying the Kullback-Leibler divergence by the amount of to-be-remembered
267 items n . Note that here, swap errors are counted towards the computation of memory capacity κ .
268 Although swap errors originate from information that was bound to the wrong item, this
269 information was stored in visual short-term memory, and should thus count towards its maximum
270 capacity.

271

$$272 \quad \kappa = n \int_{-\pi}^{\pi} p(x) \log_2 \frac{p(x)}{q(x)} dx \quad (2)$$

273 Where:

$$274 \quad p(x) = (1 - \gamma) \phi_{\sigma}(x) + \gamma \frac{1}{2\pi} \quad (3)$$

275

$$276 \quad q(x) = \frac{1}{2\pi} \quad (4)$$

277

278 The final estimate for each participant's visual short-term memory capacity was obtained by
279 averaging the estimates of κ obtained from the 2-item and 4-item conditions. The associated unit is
280 *bits* of information.

281

282 Joint visual short-term memory task

283 We designed a joint short-term memory task that was similar in concept to the individual
284 task described above (**Figure 2**). In each trial, a pair had to memorise a total of eight items (the
285 same sinusoidal gratings as in the individual task). After a maintenance period of 3 seconds, each

286 individual was probed to recall one of the items. Responses could again be given by using the
287 mouse to precisely indicate the memorised orientation, as in the individual task. Individual
288 participants within each pair were rewarded with points for their performance (see below for the
289 exact reward scheme). They were shown both their own reward, and the reward that their partner
290 obtained. These rewards were then added together, and equally divided between the participants.
291 Hence, participants were not only incentivised to do well, but also to help their collaborator do well.

292 Crucially, the individuals in each pair were allowed to claim their own share of the items.
293 They could claim an item by looking at an item for 150 ms or longer. After a participant claimed an
294 item, a light shading appeared behind it on their own screen, and a dark shading appeared behind
295 the same item on the other participant's screen. Participants could not claim items that were already
296 claimed. Only claimed items would be probed for a response. If a participant did not claim any
297 items, no item would be probed, and they would be assigned a reward of 0 points. This occurred in
298 only 1 out of all 800 trials. (In this scenario, the other participant would have to claim and
299 remember all eight items.)

300 How many items were claimed by each individual within a pair was determined by the pair.
301 They received an instruction that explicitly informed them that they were allowed to divide the
302 items between themselves and their collaborator in any way they saw fit, for example with one
303 participant claiming more than the other, or with both participants claiming equally many. They
304 were also instructed that their pair should attempt to obtain as many points as possible. There was
305 no communication between the individuals beyond being able to see which items were claimed by
306 themselves, and which by their collaborator.

307 Pairs were constructed by randomly assigning two participants to the same game. Each pair
308 completed 25 trials, after which each individual indicated on a visual analogue scale how good they
309 thought the collaboration was, how fair they thought their collaborator was, and how likeable they

310 thought their collaborator was. Each individual took part in two or three consecutive collaborative
311 sessions.

312

313 Performance-dependent group reward

314 Choosing the appropriate reward scheme for the joint visual short-term memory task was
315 not a trivial matter. Ideally, individuals were rewarded as a function of their performance. Here,
316 performance (recall error) was defined as the absolute circular difference between the prompted
317 target's orientation and the associated response. This error existed in a space between 0 degrees
318 (perfect recall) and 90 degrees (the largest possible circular distance between target and response).
319 The most straightforward scheme would entail a linear relationship between individuals' recall error
320 and their reward. However, recall error is rarely uniformly distributed: Participants are generally
321 more likely to respond around 0 error, with the exact shape of the distribution depending on their
322 visual short-term memory capacity κ . A non-linear reward scheme, such as a normal distribution,
323 could address this.

324 We anticipated three ways to play the joint visual short-term memory game outlined above.
325 The first option was an **equal** division of labour, with each participant claiming half of the items to
326 remember.

327 The second option was a **proportional** division of labour, with each participant claiming a
328 proportion of the items that corresponded to the ratio of participants' visual short-term memory
329 capacities. For example, if one participant's capacity κ was 4 bits and the other participant's was 2.4
330 bits, a proportional division of 8 items would have had the higher-capacity participant claim 5 and
331 the lower-capacity participant claim 3.

332 Finally, there was a **paradoxical** division of labour, which could have been optimal
333 depending on how strongly the reward scheme penalised higher errors. Specifically, if low errors

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334 were to receive disproportionally larger rewards, the optimal strategy would have been to have the
335 lower-capacity player claim all but one item. The higher-capacity individual would have then
336 claimed only one item, and would thus have achieved a very high reward.

337 To illustrate the effect of different reward functions, we simulated the expected joint rewards
338 between two players of different visual short-term memory capacities κ who divided labour equally,
339 proportionally, or paradoxically (**Figure 3**).

340 When only very low errors would receive a high reward (normal distribution with a low
341 standard deviation), a paradoxical division of labour would be optimal, whereas it would be hard to
342 predict when proportional division would work in a pair's favour (**Figure 3**, top row).

343 When higher errors would be punished less severely (e.g. via a normal distribution with a
344 high standard deviation, or a linear function), paradoxical division of labour would become less
345 ideal. However, although optimal, proportional division would give only a small benefit (**Figure 3**,
346 bottom two rows).

347 The ideal reward function would incentivise proportional division of labour while not
348 making paradoxical division of labour too tempting. Our simulations indicated that this ideal reward
349 function was a normal distribution with a standard deviation that resulted in the incentivisation of
350 low errors without penalising higher errors too strongly (**Figure 3**, second row).

351 Because of the outlined simulations, we opted for defining our individual reward function as
352 a normal distribution with a standard deviation of 17 degrees (centred around 0 degrees). This
353 corresponded with the average standard deviation of errors in a pilot experiment using coloured
354 stimuli (Dalmaijer, Poullias, Somai, & Husain, 2017).

355

Figure 3 – Different reward schemes and their expected outcomes for players of different short-term memory capacities. The leftmost column illustrates the reward function, with error (absolute difference in degrees of response and stimulus orientation) on the x-axis, and reward on the y-axis. The second, third, and fourth column show the expected reward under three different strategies. In the equal strategy, collaborators divide items equally. In the proportional strategy, participants divide items proportionally to their visual short-term memory capacity. In the paradoxical strategy, the lower-capacity player takes on all but one of the items, and the higher-capacity player takes on only one item. The x-axis denotes the visual short-term memory capacity of the first player, and the y-axis that of the second player. The colouring indicates the expected group reward, with brighter colours indicating higher rewards. Finally, the penultimate and rightmost columns indicate the relative improvement of the proportional and paradoxical strategies compared to equal division. These columns show that steep reward functions (disproportionality rewarding lower errors) result in high expected benefits from the paradoxical strategy, whereas less steep reward functions do not. However, less steep reward functions also decrease the expected benefit from using a proportional strategy. The optimal reward function, which incentivises the proportional strategy but not the paradoxical, seems to lie in the middle.

358 **Statistical analyses**

359 We considered each of the 32 unique pairs an independent measurement. We divided the
360 individuals within each pair as “higher capacity” and “lower capacity”, according to their visual
361 short-term memory capacity that was independently determined through the individual assessment.

362 Our main hypothesis was that within each pair, the higher-capacity individual would claim
363 more items than the lower-capacity individual. To test this, we used an independent-samples t-test to
364 test whether the average number of claimed items was different between the higher and lower-
365 capacity individuals. We also hypothesised the difference in claimed items would correlate with
366 how participants rated the collaboration, and thus used a linear regression to verify whether the
367 difference in claimed items (relative to the difference in capacity) predicted collaboration
368 judgement of both participants within a pair.

369 Earlier research indicated that in joint visual search, two collaborators divide items in search
370 space, for example by dividing the field in a top and a bottom half (Brennan et al., 2008; Niehorster
371 et al., submitted). To assess whether this pattern also emerged in our data, we computed the average
372 location of all items claimed by each individual. We then computed the average distance, and the
373 standard deviation of the distance (across trials) between each individuals’ average item location.
374 The average unsigned distance reflects the extent to which individuals divided the space, and the
375 standard deviation reflects how consistent they were in dividing the space in the same way. We
376 correlated these two outcome measures with the ratings each player assigned the collaboration
377 quality, and the fairness and likeability of their collaborator.

378 Finally, to assess the effects of personality traits on division of labour, we computed the
379 differences in personality questionnaire scores between the higher-capacity and lower-capacity
380 individuals within each pair. We then used a multivariable linear regression with the difference in

381 capacity as co-variate, as well as the differences in the subscales of the Apathy Motivation Index
382 (Ang et al., 2017) and Big Five personality traits (Gosling et al., 2003) questionnaires.

383 Because of our relatively low number of samples, we used Kendall's rank correlation
384 coefficient τ (Kendall, 1938). This coefficient requires fewer samples than Spearman's and
385 Pearson's correlation coefficients to obtain the same confidence interval (Bonett & Wright, 2000).
386 Specifically, to detect a strong effect (Pearson $R > 0.8$, equivalent to Kendall $\tau > 0.6$) with a Fisher
387 confidence interval width of 0.3 at an α level of 0.05, one would need a sample of 35 (Bonett &
388 Wright, 2000).

389 Note that our sample size was limited primarily due to practical limitations: We depended on
390 the likelihood of a large number of participants to be available at the same time. As a result, we
391 were left with sufficient power to detect strong effects, but not necessarily to detect weaker effects.
392 In addition, we required quite a few comparisons to address our hypotheses. We thus decided on the
393 rather conservative Bonferroni correction for multiple comparisons (Dunn, 1961). Specifically, we
394 set the statistical significance threshold α to 0.05, and performed 23 tests, plus a multivariable
395 regression with 9 predictors (which includes 1 F -test, and 10 t -tests). We thus set our corrected
396 significance threshold to 0.0015 (equivalent to a correction of 34 independent tests). All p values at
397 or below this level will be considered statistically significant.

398

399 Open methods and data

400 Both experiments were programmed in Python (Dalmaijer, 2017; Van Rossum & Drake,
401 2011), using the PyGaze (Dalmaijer, Mathôt, & Van der Stigchel, 2014) and PsychoPy (Peirce,
402 2007) packages. Data extraction, analysis, and visualisation were also performed in Python, using
403 the NumPy and SciPy libraries (Oliphant, 2007), and the Matplotlib package (Hunter, 2007).

404 Visualisation colours were selected from the colourblind-friendly ‘points of view’ palette (Wong,
405 2011). The multivariable regression was performed in JASP, version 0.9.0.1 (JASP Team, 2016).

406 All code and data has been made available online, in a repository hosted on GitHub:

407 https://github.com/esdalmaijer/2017_Lund_Collaborative_short-term_memory_game.

408

409

410 Results

411

412 Manipulation checks

413 There was a good range in the distribution in errors and associated visual short-term
414 memory capacities computed from the individual assessments (**Figure 4A**). The associated visual
415 short-term memory capacities ranged from $\kappa=1.41$ to $\kappa=5.65$ bits, with a mean of 3.62, and a
416 standard deviation of 1.22. This means our sample showed reasonable variance in short-term
417 memory capacity, in line with population estimates (Luck & Vogel, 2013).

418 In the joint visual short-term memory task, participants were paired up randomly to form
419 pairs, and our analyses focussed on whether within a pair the lower-capacity individuals would
420 differ from higher-capacity individuals (for the spread in capacity differences, see **Figure 4A-B**).
421 Indeed, the lower-capacity individuals showed higher recall errors than their higher-capacity
422 collaborators [$t=-4.19$, $p<0.001$] (**Figure 4C**). Consequently, they contributed significantly fewer
423 points to the group total [$t=-4.73$, $p<0.001$] (**Figure 4D**).

424

Figure 4 – A) Histograms showing the probability density of errors in the individual visual short-term memory assessment of all participants. The narrower the curve, the higher the associated short-term memory capacity. **B)** When pairs are sorted according to relatively differences in short-term memory capacity, the lower-capacity and higher-capacity individuals show a large variety in capacity differences. **C)** Across all pairs, lower-capacity individuals (blue) produce higher average absolute errors than higher-capacity individuals (pink). **D)** Across all pairs, lower-capacity individuals (blue) contribute fewer points to the group reward than higher-capacity individuals (pink). Plots show individual samples as coloured dots, observation density in a violin plot, and group median and quartile ranges (plus ‘outliers’ as black dots) as box-plots nested in the violin plots. Observations from the same pair are connected by grey lines.

No capacity-dependent division of labour

Our hypothesis was that players would divide the number of items between themselves according to their capacities. However, there was no significant difference in how many items were claimed by the lower and higher-capacity individuals in the joint visual short-term memory game, $[t=0.00, p=1.000]$ (**Figure 5A**).

In addition, we computed the capacity ratios of all pairs, where higher numbers indicated a larger discrepancy between the players. We also computed the ratio in the number of items each player claimed, where higher numbers again indicated a larger discrepancy between players. If our hypothesis were true, there should have been a significant correlation between the players' capacity ratio and their claim ratio. This correlation was not observed [$\tau = -0.18$, $p = 0.151$], and in fact nearly all claim ratios were instead close to 1 (**Figure 5B**).

These results indicate that participants divided labour equally rather than proportionally.

Figure 5 – A) When pairs are sorted according to relatively differences in short-term memory capacity, the lower-capacity and higher-capacity individuals do not differ in how many items each claims. Individual samples are shown as coloured dots, observation density in a violin plot, and group median and quartile ranges (plus ‘outliers’ as black dots) as box-plots nested in the violin plots. Observations from the same pair are connected by grey lines. **B)** There is no correlation between the ratio of visual short-term memory capacity within each pair, and the ratio between the number of claimed items within each pair. In fact, the vast majority of claim ratios lies around one, indicating most pairs divided items roughly equally.

Division of labour does not affect collaboration perception

To assess whether the division of labour affected collaboration perception, we computed the discrepancy between expected (based on capacity ratios) and actual (based on claim ratios) division

445 of labour. This was simply the signed difference between the claim ratio and the capacity ratio
446 (claim minus capacity), where positive values indicated that the higher-capacity player within a pair
447 claimed more items than they should have (if players divided items proportionally to their
448 capacities), and negative values that the lower-capacity player over-claimed.

449 We hypothesised that players would have rated the collaboration better when they and their
450 collaborator had shared items proportionally. Hence, we expected a correlation between the
451 difference in claim and capacity ratios on the one hand, and the average collaboration rating on the
452 other. However, there was no statistically significant relationship between the claim-capacity
453 disproportionality and the rating of how good the collaboration was given by higher-capacity
454 individuals [$\tau=0.01$, $p=0.961$], nor with that given by lower-capacity individuals [$\tau=0.09$, $p=0.484$]
455 (**Figure 6A**). The same was true for the ratings given by higher-capacity [$\tau=-0.10$, $p=0.426$] and
456 lower-capacity individuals' [$\tau=0.31$, $p=0.014$, not significant at $\alpha=0.0015$] of how fair the other
457 player was (**Figure 6B**), and for the ratings given by higher-capacity [$\tau=0.04$, $p=0.733$] and lower-
458 capacity individuals' [$\tau=-0.03$, $p=0.833$] of how likeable the other player was (**Figure 6C**).

459 These results indicate that participants did not factor in proportional division of labour in
460 their appreciation of the quality of their collaboration, or the fairness or likeability of their
461 collaborator.

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Figure 6 – Correlations between the disproportionality between the visual short-term memory capacity and claimed items ratios within each pair. Negative disproportionality values (x-axis) indicate the lower-capacity player (blue) claimed more items than they perhaps should have given their short-term memory capacity, whereas positive values indicate the higher-capacity player (pink) claimed more. A disproportionality of 0 constitutes perfectly proportional division of labour. There was no correlation between disproportionality and ratings of collaboration quality (A), collaborator fairness (B), and collaborator likeability (C) given by either of the participants.

Collaboration perception was driven by behavioural volatility

We hypothesised that division of items according to their position on the screen would affect collaboration perception. Specifically, participants in joint visual search have been shown to regularly divide the item space in two halves, even when their only means of communication was real-time feedback on where the other participant was looking (Brennan et al., 2008). Because the spatial structure and feedback matches this type of experiment, we hypothesised that adherence to the same type behaviour would have positively affected collaboration perception.

To verify this, we computed the average location of items claimed within each trial by each participant within a pair. We then computed the average distance between these locations within each pair, where higher values indicated that participants divided the search space to a higher degree. In addition, we computed the standard deviation of the distance between the players within each pair, where higher values indicated less consistent behaviour.

There were no statistically significant correlations between the average inter-player distance and collaboration ratings given by higher-capacity [$\tau=0.17, p=0.178$] or lower-capacity individuals

481 [$\tau=0.15$, $p=0.248$], or with the collaborator fairness ratings given by higher-capacity [$\tau=0.00$,
 482 $p=0.987$] or lower-capacity individuals [$\tau=-0.07$, $p=0.569$], or with the collaborator likeability
 483 ratings given by higher-capacity [$\tau=0.13$, $p=0.307$] or lower-capacity individuals [$\tau=-0.03$, $p=0.783$]
 484 (**Figure 7**, top row).

485 There were statistically significant relationships between the standard deviation of the inter-
 486 player distance and ratings given by higher-capacity individuals on good collaboration [$\tau=-0.49$,
 487 $p<0.001$], collaborator fairness [$\tau=-0.42$, $p<0.001$], and collaborator likeability [$\tau=-0.42$, $p<0.001$].
 488 Although lower-capacity players showed the same pattern, the relationship between the standard
 489 deviation of the inter-player distance and ratings given by lower-capacity individuals on good
 490 collaboration [$\tau=-0.32$, $p=0.011$], collaborator fairness [$\tau=-0.17$, $p=0.188$], and collaborator
 491 likeability [$\tau=-0.23$, $p=0.067$] were not statistically significant at our corrected α level of 0.0015. It
 492 should be noted that the distance variability did not correlate with task performance as measured by
 493 joint reward [$\tau=-0.12$, $p=0.347$] (**Figure 7**, bottom row).

494 These results indicate that at least the higher-capacity players rated the quality of
 495 collaboration, as well as the fairness and likeability of their collaborator, lower as a function of the
 496 variability of the distance between each collaborators' claimed items. This was true despite this
 497 variability not affecting group performance.

498

499

Figure 7 – Top row: The distance between the average location of items claimed by the higher-capacity (pink) and lower-capacity individual (blue) within each pair did not correlate with individuals' ratings of how good the collaboration was (A), how fair the collaborator was (B), or how likeable the collaborator was (C). **Bottom row:** The variability in distances between the average location of items claimed by the higher-capacity (pink) and lower-capacity individual (blue) within each pair did correlate with individuals' ratings of how good the collaboration was (D), how fair the collaborator was (E), or how likeable the collaborator was (F); at least for those given by higher-capacity players. (Correlations for ratings given by lower-capacity players were in the same direction, but not statistically significant at our corrected α level of 0.0015.)

500

501 Apathy and Big Five traits affect number of claimed items

502 A secondary objective of our study was to assess the effects of apathy as measured by the
503 Apathy Motivation Index (Ang et al., 2017) and Big Five personality traits as measured via a brief
504 questionnaire (Gosling et al., 2003) on the number of items participants claim. Within each pair, we
505 computed the difference between the higher-capacity and lower-capacity player in the following
506 independently assessed traits: visual short-term capacity (measured in our independent assessment);
507 behavioural activation apathy, social motivation apathy, and emotional stability (Apathy Motivation
508 Index subscales); extraversion, agreeableness, conscientiousness, emotional stability, and openness
509 (Big Five subscales). We then used these nine differences as co-variates in a linear multivariable

510 regression to predict the differences in the average number of claimed items between the higher and
511 lower capacity players within each pair.

512 The total difference in the number of claimed items was statistically significantly predicted
513 by the complete model [$F(9,22) = 5.81, p < 0.001$]. Significant predictors of the difference in the
514 number of claimed items were social motivation apathy [$t = 4.116, p < 0.001$], and conscientiousness
515 [$t = -3.67, p = 0.001$]. These results indicate that pairs with a higher difference in social motivation
516 and conscientiousness also showed a higher difference in the number of claimed items.

517 Non-significant predictors at the α level of 0.0015 were the differences in visual short-term
518 memory capacity [$t = 1.84, p = 0.079$], behavioural activation apathy [$t = -1.86, p = 0.077$], emotional
519 stability [$t = 1.60, p = 0.124$], openness [$t = 2.19, p = 0.040$], extraversion [$t = 1.58, p = 0.130$], and
520 agreeableness [$t = 1.49, p = 0.150$]. Emotional stability as measured with a short-form Big Five
521 questionnaire did not reach statistical significance at the α level of 0.0015 [$t = 3.49, p = 0.002$].

522 Although higher differences in social motivation apathy work in the opposite direction to
523 higher differences in conscientiousness, it is hard to establish the exact origin of these effects. This
524 is because they were computed using difference scores, and are dependent on the co-variation of
525 other variables.

526

527

528 Discussion

529

530 In a new collaborative visual short-term memory task, we leveraged individual differences
531 in cognitive ability, and employed a non-linear performance reward structure to incentivise
532 collaboration between randomly assigned pairs of participants. Paired individuals did not know who

533 their collaborator was, and could not communicate verbally, but they did receive real-time feedback
534 on each other's behaviour. Our results indicate that collaborators did not share their cognitive
535 workload proportionally to their individual capacities, but instead divided labour equally.
536 Furthermore, the lack of adherence to proportional division did not affect individuals' ratings of the
537 collaboration's quality, nor their collaborator's fairness or likeability. Instead, collaboration ratings
538 correlated strongly with the variability in the distance between locations of items claimed by each
539 individual. Interestingly, this variability did not correlate with individuals' performance, and was
540 thus irrelevant to the task. Finally, our results suggest that individual differences in social apathy
541 and conscientiousness correlated with differences in the proportion of labour within a pair.

542 Others have recently demonstrate the existence of an equality bias among collaborators who
543 had to make a shared perceptual decision (Mahmoodi et al., 2015). That work suggested pairs of
544 collaborators value each other's opinion equally, even when one collaborator was markedly better
545 (whether naturally, or through experimenter manipulation). What remained unclear was whether a
546 discrepancy in collaborators' ability would prompt the higher-ability individual to help the lower-
547 ability individual.

548 Our task differed from Mahmoodi and colleagues' study in that it allowed collaborators to
549 divide labour amongst themselves. Because they received feedback after each trial, collaborators
550 were given the opportunity to assess the difference in ability between them. Furthermore, they were
551 subject to a non-linear group reward scheme that incentivised not only individuals' own
552 performance, but also that of their collaborator. Hence, in our experiment collaborators had
553 information on each other's ability, were able to act on their ability discrepancy by proportionally
554 dividing labour, and also incentivised to do so to maximise reward. However, the vast majority of
555 collaborators opted for dividing items equally, which suggests that the equality bias in opinions
556 demonstrated by (Mahmoodi et al., 2015) extends to the division of labour.

557 Another interesting finding we highlight here is that individuals' rating of the quality of
558 collaboration was unaffected by whether or not labour was shared equally. In fact, particularly the
559 higher-ability individual within each pair instead rated the collaboration quality less high as a
560 function of the variability in their pair's behaviour. Specifically, if the distance between their own
561 and their collaborator's average location of claimed items varied a lot between trials, they were
562 more likely to rate the collaboration as less good, and also to rate their collaborator as less fair and
563 less likeable. This is despite the fact this distance variability did not correlate with performance, and
564 was thus unrelated to reward.

565 Earlier work suggests that participants in collaborative cognitive tasks prefer to divide their
566 workspace in halves (Brennan & Enns, 2015; Brennan et al., 2008; Neider et al., 2010), and
567 minimise overlap in self-assigned workspace (Niehorster et al., 2019). This maximises the distance
568 between collaborators, perhaps so they avoid getting in each other's way. Our work suggests that it
569 is not the distance between collaborators, but instead the trial-to-trial consistency in distance that
570 determines the perceived collaboration quality. Hence, behavioural stability is a trait that individuals
571 seem to prefer in their collaborators.

572 Finally, the results presented here indicate that inter-collaborator differences in cognitive
573 ability (visual short-term memory capacity) did not drive labour division, but that differences in
574 personality traits do. Specifically, inter-collaborator differences in lack of social motivation, or
575 'social apathy' (Ang et al., 2017), correlated with differences in the number of items each claimed.
576 The same is true for the Big Five personality trait conscientiousness, albeit in the opposite direction.
577 Note that these findings should be interpreted more carefully, as they originate from difference
578 scores (which obscure directionality), and because they originate from a model with a large number
579 of co-variates.

580 Limitations and future directions

581 We should note that the research presented here is highly exploratory, and that our sample of
582 32 pairs only provided enough statistical power to detect large effects. We took this into account in
583 our statistical analyses by being conservative and applying a stringent Bonferroni correction,
584 resulting in a statistical significance threshold of 0.0015. Although we are reasonably confident that
585 the behavioural effects we report are robust, we would like to stress the possibility of smaller effects
586 having gone undetected. We have published our methods and data in a public repository, and invite
587 other researchers to use these tools to replicate and extend our findings (see
588 https://github.com/esdalmajjer/2017_Lund_Collaborative_short-term_memory_game).

589 There are several potential explanations for why participants divided their cognitive labour
590 equally in our joint visual short-term memory task. We interpret this finding as an extension of
591 previously reported equality bias (Mahmoodi et al., 2015). However, one could also take
592 participants' reluctance to unequal division of labour as a protection against "free loading": Perhaps
593 higher-capacity individuals did not want lower-capacity individuals to benefit from their additional
594 labour. Although our reward scheme would have ensured the higher-capacity individual in this
595 scenario to also benefit from proportionally shared labour, it cannot be ruled out that higher-
596 capacity individuals either did not pick up on this, or weighted preventing "free loading" over their
597 own increase in reward. Finally, one could argue that our reward scheme was too complicated for
598 participants to comprehend, particularly because they were not allowed to communicate, and that
599 this made them default into equal sharing. Although readers of this manuscript can appreciate the
600 complexity of the employed reward scheme, individual participants in our experiment could not: To
601 them, better recall accuracy translated into higher rewards, particularly when their own *and their*
602 *partner's* recall were highly precise. This direct dependency on not just their own recall precision
603 but also their partner's was made very apparent in every trial's feedback screen.

604 Future studies could adopt the tools presented here to investigate what drives equal sharing
605 of labour. The results presented here do not conclusively distinguish between competing
606 explanations: Are participants unable to determine their partner's short-term memory capacity from
607 feedback, do they not consider capacity in their judgement of what division is fair, or are they more
608 concerned with preventing "free loading"? This could in part be investigated by asking participants
609 to rate their partners' capacity, or by explicitly telling pairs what each individual's capacity is.

610 It would be interesting to follow up our finding that more stable division of stimulus space
611 was related to better collaboration ratings. Researchers could implicitly encourage pairs to divide
612 the stimuli by introducing a visual divide between two groups of stimuli, for example through
613 different colouring or spatial separation. This should lead to improved collaboration ratings over the
614 randomised stimulus locations employed here.

615

616 Conclusion

617 In conclusion, we explored collaborative behaviour in a novel joint visual short-term
618 memory task, and found that collaborators divide cognitive labour equally between them. This was
619 true even when there was a large discrepancy between collaborators' (independently assessed)
620 short-term memory capacities, and when dividing labour proportionally would have yielded higher
621 group rewards. Paradoxically, participants did not weigh proportional division of labour into their
622 rating of collaboration quality. Instead, high collaboration ratings were associated with low
623 behavioural variability, despite this not relating to group performance.

624 We conclude that in a collaborative task with clear performance feedback but without verbal
625 communication, individuals prefer to divide labour equally and in a consistent pattern, even when
626 proportional division would be optimal.

627

628 **References**

629

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