Response bias reveals the role of interhemispheric inhibitory networks in movement preparation and execution

Rohan Puri ^{a*} and Mark R. Hinder ^a

^a Sensorimotor Neuroscience and Ageing Research Group, School of Psychological Sciences, College of Health and Medicine, University of Tasmania, Hobart, Australia

* Corresponding Author

Rohan Puri
Sensorimotor Neuroscience and Ageing Research Group, Private Bag 30,
School of Psychological Sciences, College of Health and Medicine,
University of Tasmania,
Hobart, TAS 7001
Australia
E: rohan.puri@utas.edu.au
P: +61 3 6226 2558

Abstract

Human movement is influenced by various cognitive processes, such as *bias*, that dynamically shape competing movement representations. However, the neurophysiological mechanisms underlying the effects of bias on movement selection across the lifespan remains poorly understood.

Healthy young ($n = 21$) and older ($n = 20$) adults completed a choice reaction time task necessitating left- or right-hand responses to imperative stimuli (IS). Response bias was manipulated via a cue that informed participants a particular response was 70% likely (i.e., the IS was either congruent, or incongruent, with the cue); biasing was either fixed for blocks of trials (block-wise bias) or varied from trial-to-trial (trial-wise bias). As well as assessing the behavioural manifestations of bias, we used transcranial magnetic stimulation to determine changes in corticospinal excitability (CSE) and short- and long-interval interhemispheric inhibition (SIHI, LIHI) during movement preparation and execution.

Participants responded more quickly, and accurately, in congruent compared to incongruent trials. CSE decreases occurred in *both* hands following the cue, consistent with the 'inhibition for impulse control' hypothesis of preparatory inhibition. In contrast, IHI modulations occurred in a hand-specific manner. Greater SIHI was observed during movement *preparation* in the hand biased away from, compared to the hand biased towards, the cue; furthermore, greater SIHI was observed during movement *execution* in the hand biased towards the cue when it was not required to respond (i.e., incongruent trial) compared to when it was required to respond (congruent trial). Additionally, during the movement preparation period, the LIHI ratio of the hand biased towards, compared to the hand biased away from, the cue was greatest when the cue varied trial-by-trial.

Overall, the IHI results provide support for the 'inhibition for competition resolution' hypothesis, with hand specific modulation of inhibition during movement preparation and execution.

Keywords (maximum 6)

Movement preparation
Movement execution
Response Bias
Transcranial magnetic stimulation
Interhemispheric inhibition
Ageing

1. Introduction

Movement is arguably the most fundamental way in which humans interact with the constantly changing world around them. Goal-directed movement requires navigating through different movement choices - influenced to varying degrees by upstream cognitive processes - with the aim of ultimately selecting and executing the most appropriate movement (Bestmann and Duque, 2016; Cisek, 2007). Even seemingly effortless movements - such as picking up a cup of tea or walking across the street - are influenced by cognitive processes determining the shape of the cup and the temperature of the tea, or the surface of the street and the speed of oncoming cars, for example. Thus, the relative simplicity by which one executes volitional movements belies the complexity of the neural mechanisms engaged in selecting and preparing those movements.

One of the most common paradigms used to investigate movement preparation, and the associated neural mechanisms, is the 'delayed reaction-time' task (Duque et al., 2017). Herein, a preparatory cue (or warning signal) is provided prior to an imperative stimulus to which a response is required. Such cues should facilitate faster and more accurate responses to the imperative stimulus, compared to when no such information is provided. For example, in a choice reaction-time task requiring left or right finger responses, a preparatory cue could provide unambiguous (categorical) information that the upcoming imperative cue requires a left finger response. Behaviour (and neural mechanisms) in this scenario can then be contrasted to those observed when the cue signals a right finger response will be required, or scenarios where no such cue is provided, or where a cue is not informative (Greenhouse et al., 2015; Hasbroucq et al., 1997; Thierry Hasbroucq et al., 1999; Hinder et al., 2018; Ibáñez et al., 2020; Lebon et al., 2016; Tandonnet et al., 2010; Vassiliadis et al., 2018). By applying transcranial magnetic stimulation (TMS) over the primary motor cortex (M1) and quantifying the amplitude of the resulting motor-evoked potential (MEP) as a measure of corticospinal excitability (CSE), researchers have gained insight into the neural mechanisms underlying movement preparation. The most prominent observation is that of widespread *reductions* in CSE, termed "preparatory inhibition" (Bestmann and Duque, 2016; Derosiere and Duque, 2020; Duque et al., 2017), the extent of which may vary according to whether the hand is cued to respond or not.

Movement preparation has also been shown to be modulated by top-down influences and cognitive processes when preparatory cues reflect differential rewards between response alternatives (Bundt et al., 2019, 2016; Klein et al., 2012) and when sensory conflict exists in a flanker type response task (Duque et al., 2016; Klein et al., 2014). In these tasks, one's perceptual judgement or perceived value of a reward may have more influence on the preparation of the movements, compared to when the cue provides unambiguous information (i.e., that one hand will, or will not, have to respond). By providing preparatory cues that indicate the *likelihood* that a particular response will be required, rather than unambiguous categorical cues, we can investigate how response *bias*, and the perceptual interpretation thereof, affects the mechanisms underlying movement preparation. Indeed, in many everyday situations, we only have bias or likelihood information as opposed to categorical information of which response alternative will be required. For example, when returning serve in tennis, you may assume – based on experience – that your

130 opponent is more *likely* to serve to your forehand, although this, of course, is not a
131 certainty. Bestmann and colleagues (2008) provided some initial findings, suggesting
132 greater CSE for the hand biased toward, than away from, the preparatory cue,
133 however, a number of questions remain unanswered. The current study aims to
134 provide novel insights in three distinct areas.

135
136 Firstly, we aim to elucidate the degree of *flexibility* in how we utilise bias cues to
137 facilitate improved performance. Specifically, bias towards a response can either be
138 held constant across a large number of consecutive trials (e.g., as per Bestmann et
139 al. 2008, a “85% left” preparatory cue in a choice RT task indicates that 85% of all
140 imperative cues will require a left finger response), or varied from trial-to-trial (e.g.,
141 “85% left” and “85% right” preparatory cues are intermingled). Note that in both
142 scenarios, the information presented by the cue is 100% valid, i.e., the true likelihood
143 of the biased response being required is always 85%. Garton and colleagues (2019
144 – see their supplementary materials file) failed to observe statistically significant
145 differences in the extent to which bias cues were utilised in a perceptual decision-
146 making task when the cue was varied in a block-wise, or trial-wise manner. However,
147 the behavioural and computational modelling approaches utilised therein did not
148 assess whether neurophysiological processes differed in the trial-wise and block-
149 wise conditions. It may therefore be the case that more cognitive control over
150 movement preparation (evidenced by changes in TMS measures) was required in
151 the scenario where cues had to be actively interpreted on a trial-by-trial basis to
152 maintain comparable behavioural performance. Such a postulation may be
153 supported by Greenhouse et al. (2015) who observed different degrees of
154 preparatory inhibition (measured by TMS) when *task requirements* (choice vs. simple
155 RT task) were held constant for each block of trials, or varied trial-by-trial. The
156 current study thus addressed whether neurophysiological measures of movement
157 preparation differed according to *how* response bias was manipulated.

158
159 Secondly, we wished to determine how *healthy ageing* affects both behavioural and
160 neurophysiological measures of response bias. Projections suggest that over the
161 next three decades the number of people aged 65 years and above will not only
162 double but also increase its share of the population from 9.3% to 16.0% (United
163 Nations 2020). Considering this, there has been a disproportionate lack of research
164 on the effect of healthy ageing on movement preparation in general, let alone its
165 effect on response bias, which the current study aims to address. Garton and
166 colleagues (2019) reported that older adults were indeed able to maintain the use of
167 bias cues, with equally flexible (and potentially more optimal, from an evidence
168 accumulation perspective – see Garton et al., 2019) use of cues compared to
169 younger adults. Given the well documented changes in structure and function of
170 cortical brain regions across the lifespan, especially in regards to inhibitory
171 mechanisms (Hermans et al., 2018; Strauss et al., 2019; Talelli et al., 2008), it
172 remains to be determined whether this maintenance of behavioural responses to
173 bias was a result of similar, or distinct, neurophysiological mechanisms including
174 preparatory inhibition.

175
176 Finally, the vast majority of research investigating movement preparation has utilised
177 unconditioned TMS to elicit MEPs and interpret changes in MEP to reflect changes
178 in CSE (Derosiere et al., 2020; Duque et al., 2017). Thus, the notion of preparatory
179 inhibition relies upon interpretation of the MEP from unconditioned TMS that reflects

180 the summed output of direct and indirect (spinal, intra-, inter-, and sub-cortical)
181 activation of corticospinal neurons, with little nuance in regards to what *specific*
182 neural networks may be involved (Bestmann and Krakauer, 2015). Amongst other
183 more flexible approaches, single- and dual-site conditioned TMS protocols can offer
184 additional insight into cortical networks underlying movement preparation (Derosiere
185 et al., 2020). Indeed, the influence of GABAergic intracortical circuits, assessed via
186 short-interval intracortical (SICI) protocols, subserving movement preparation has
187 been relatively well-established (Duque and Ivry, 2009; Sinclair and Hammond,
188 2009, 2008; Tandonnet et al., 2010) with more recent research implicating
189 GABAergic intercortical circuits as well via inter-hemispheric inhibition (IHI) protocols
190 (Hinder et al., 2018). Given the involvement of movement representations involving
191 both M1s in the current study, TMS protocols probing not only CSE in both M1s but
192 also intercortical inhibitory networks between the two M1s were utilised to provide
193 additional neurophysiological insights. Our previous work (Hinder et al. 2018)
194 suggested that changes in CSE and IHI would reflect distinct movement preparation
195 and execution related processes, which may be differently affected by response
196 bias.

2. Materials & methods

2.1 Participants

Forty-one healthy adults, consisting of 21 young adults (mean age = 26.76 years; SD = 5.85 years; range = 19 to 40 years; all but two self-declaring right-handed dominance) and 20 older adults (mean age = 67.95 years; SD = 5.12 years; range = 61 to 84 years; all but one self-declaring right-handed dominance) were recruited from the university and wider local community (recruitment was only advertised for adults between 18 and 40 years and adults 60 years and over to meet the requirement of a 'young' and 'older' age group, respectively). Older adults were screened for cognitive deficits using The Mini-Mental State Examination (Dick et al., 1984) with all older participants scoring within a normal range (score ≥ 26 ; Jacqmin-Gadda et al., 1997). Contraindications to transcranial magnetic stimulation (TMS) were assessed via a medical history questionnaire and all participants were free of any known neurological or neuromuscular dysfunction. All participants provided written informed consent prior to participating in the study which was conducted in accordance with the Declaration of Helsinki and approved by the Tasmanian Human Research Ethics Committee Network.

2.2 Experimental procedure

Participants attended two sessions (each 1.5 - 2.5 hours duration), on separate days at least 24 hours apart (mean duration between sessions = 6.2 days), with the first session involving only the behavioural task (i.e., no TMS administration; "behaviour only session") and the second session involving the behavioural task in conjunction with TMS administration ("combined session").

In both sessions, participants were seated with their forearms pronated and resting on a horizontal surface, completing a choice reaction time task requiring fast-as-possible responses (with left or right index fingers) to simple visual imperative stimuli (IS) presented on a computer screen. The likelihood of an IS was determined by way of a warning stimulus (i.e., biasing cue) presented prior to the imperative stimulus. On each trial, the warning stimulus (WS), "70% <" or "70% >", was centrally presented for 500 ms indicating the true probability of the upcoming IS pointing in the same direction. Following the WS, a 250 ms blank screen, a 500 ms central fixation cross (+), and a 250 ms blank screen were presented in the stated temporal order. Subsequently, a green arrow, the IS (pointing to the left, "<", or pointing to the right, ">") was presented for 1000 ms, to which participants had to respond using their left (to "<" IS) or right (to ">" IS) index finger, as quickly and accurately as possible, by pressing buttons on a USB response pad (The Black Box ToolKit, Sheffield, UK). Trials where the WS and IS pointed in the same direction (i.e., "70% <" WS followed by "<" IS or "70% >" WS followed by ">" IS) are termed as *congruent* trials (70% of trials) whereas the trials where the WS and IS pointed in the opposite direction (i.e., "70% <" WS followed by ">" IS or "70% >" WS followed by "<" IS) are termed as *incongruent* trials (30% of trials) as depicted in Figure 1. Lastly, each trial concluded with feedback, displayed for 750 ms, constituting of one of the following: a) The reaction time, in seconds, if a correct response was recorded; b) "Incorrect press" if an incorrect response was recorded; or c) "Missed" if no response was recorded. Thus, the total trial duration summed to 3,250 ms. The inter-trial interval was set to

247 750 ms for the behaviour only session and 1750 ms for the combined session (to
248 allow enough time for the TMS capacitors to recharge between consecutive trials).
249 All experimental stimuli were presented using PsychoPy2 v1.84.2 (Peirce et al.,
250 2019).

a) Congruent

b) Incongruent

Figure 1 – Experimental trials. Participants were visually presented, on a computer monitor, a 500 ms warning signal (WS), indicating a 70% probability of the upcoming imperative signal (IS) pointing either in the left (<) or right (>) direction, resulting in the left and right hand being either biased towards or away from the WS (T or A, respectively, in the upper row of the hand status column). Following a 250 ms blank screen, 500 ms fixation cross, and another 250 ms blank screen, a 1000 ms green coloured IS (< or >) was either presented in the same (congruent trials; **a**) or opposite (incongruent trials; **b**) direction to the WS, resulting in the hand status of either responding or non-responding (R or NR, respectively, in the bottom row of the hand status column). Filled lightning bolts indicate one of the four possible time-points (WS, fixation, IS, and IS100) at which TMS was administered on a single trial.

264 To investigate the degree of flexibility in how response bias was implemented, trials
265 were presented using block-wise and trial-wise bias procedures. Specifically, for
266 block-wise biasing, the WS remained constant across the whole block of trials and
267 hence the more likely response option across the whole block of trials was invariant.
268 Separate blocks assessed left vs. right response bias (i.e., “70% <” versus “70% >”).
269 In contrast, for trial-wise biasing, an equal number of “70% <” and “70% >” WS trials
270 were presented (in a random order) within a block and hence the more likely
271 response option also varied from trial to trial.

272
273 For the behaviour only session, participants completed 20 blocks of 65 trials each -
274 10 blocks of the block-wise (with 5 blocks of “70% <” and 5 blocks of “70% >”
275 randomly administered) and 10 blocks of the trial-wise bias, counterbalanced across
276 participants. In each block, 5 trials were ‘catch’ trials (i.e., trials in which the WS was
277 *not* followed by the IS), where participants had to withhold a response, to ensure
278 participants were not anticipating the timing and location of the IS (Hinder et al.,
279 2018). Of the remaining 60 trials, given that the WS always indicated a 70%
280 probability and was always true, 42 were congruent trials and 18 were incongruent
281 trials (for trial-wise bias, there were thus 30 trials for each WS, of which 21 were
282 congruent and 9 were incongruent). Prior to the 10 experimental blocks of each bias
283 type, participants underwent practice blocks to ensure task familiarization (trial-wise
284 bias: one block of 22 trials; block-wise bias: one block of 11 trials for each bias
285 direction).

286
287 For the combined session, participants completed 20 blocks of 43 trials each – 10
288 blocks each of the block-wise and trial-wise bias, counterbalanced across
289 participants, with the same procedure and number of practice blocks as in the
290 ‘behaviour only’ session. In each block, 3 trials were ‘catch’ trials, as described
291 above. Of the remaining 40 trials, 28 were congruent trials and 12 were incongruent
292 trials. In this session, on every non-catch trial, TMS – either to measure corticospinal
293 excitability (CSE), short-interval interhemispheric inhibition (SIHI), or long-interval
294 interhemispheric inhibition (LIHI) (see Section 2.3) – was delivered at one of four
295 time-points. Specifically, at the beginning of the **WS** to provide a task-relevant
296 baseline of primary motor cortex (M1) activity, at the beginning of the **fixation** and
297 the beginning of the **IS** to infer movement *preparation* related M1 processing, and
298 100 ms after the beginning of the IS (**IS100**) to infer movement *execution* related
299 M1 processing. For the SIHI and LIHI conditions, the test pulse was administered at
300 these time points, with the conditioning pulse administered either 10 or 40 ms prior,
301 respectively. For CSE, a total of 160 TMS trials were administered – 16 each at WS,
302 fixation, IS, IS100 on congruent trials, and IS100 on incongruent trials, for both
303 block- and trial-wise bias types. For SIHI and LIHI, a total of 320 TMS trials were
304 administered each – 32 each at WS, fixation, IS, IS100 on congruent trials, and
305 IS100 on incongruent trials, for both bias types. For CSE, SIHI and LIHI, trials were
306 split equally between trials where TMS was first applied to the left M1 (and then to
307 the right M1) or to the right M1 (and then to the left M1). As well as the TMS
308 conducted within the task context, 50 TMS trials (10 CSE, 10 each of SIHI and LIHI
309 from the left to right M1, and 10 each of SIHI and LIHI from the right to left M1) were
310 administered at rest (i.e., out of task context) at three time-points, specifically, before
311 any behavioural blocks (i.e., prior to block 1), after completing all the block-wise *or*
312 trial-wise bias blocks (depending on whichever was done first; between block 10 and

11), and at the end after completing all the block-wise *and* trial-wise bias blocks (i.e., after block 20).

2.3 Electromyography and transcranial magnetic stimulation

For the combined session only, electromyographic (EMG) surface electrodes (Ag/AgCl) were placed over the left and right first dorsal interosseus (FDI) muscle in a belly tendon montage with the ground electrode placed ipsilaterally over the styloid process of the radius bone. Using a 16-bit AD system (CED Power1401 and CED 1902, Cambridge, UK), signals were amplified with a gain of 1000, band-pass filtered (20–1000 Hz), sampled at 4000 Hz, and stored for offline analysis. Participants' online EMG activity was monitored by the experimenter, on a computer monitor, to ensure muscle relaxation and, when necessary, participants were reminded to keep their hand quiescent between volitional button presses.

Dual coil TMS protocols (as described below) were used to assess CSE in both M1s and IHI from the left to right M1 as well as right to left M1, in the combined session. Dual coil TMS was delivered to the left and right M1 using two 'branding iron' style figure of eight coils (external diameter of each wing was ~ 70mm) connected to two Magstim 200 stimulators (Magstim Company, Dyfed, UK). Both TMS coils were held (by two different experimenters) tangentially to the scalp with the handle pointing backwards ~45° to ensure current flow in the brain was in the optimal posterior-anterior direction. Standard procedures were used to determine the motor 'hotspot' of each M1 and marked using a felt-tip pen. The branding iron style of the TMS coils permitted placement of coils on each M1 hotspot without compromising either coil's positioning. Resting motor threshold (rMT) – defined as the lowest stimulator intensity required to evoke motor-evoked potentials (MEPs) of ≥ 50µV in three out of five consecutive trials (Hinder et al., 2011, 2010) – was determined for each participants' left and right FDI at the beginning of the session.

Three different types of dual coil TMS trials were administered to specifically assess CSE as well as IHI at short and long interstimulus intervals. CSE of pathways to the left and right FDI was assessed by delivering dual coil TMS with an interstimulus interval of 1 ms to the left and right motor cortex hotspot at 130% rMT of the left and right FDI, respectively (unconditioned TMS trials, as the first TMS pulse has no known conditioning effect on the subsequent TMS pulse; Grandjean et al., 2018; Vassiliadis et al., 2018; Wilhelm et al., 2016). To determine IHI from the left to right M1 and from the right to left M1, a conditioning TMS pulse at 130% rMT was delivered to the left and right motor hotspot, respectively (Ferber et al., 1992). Short- and long-interval IHI were assessed by delivering the test pulse (to the contralateral M1) 10 or 40 ms following this conditioning pulse (conditioned TMS trials; Chen, 2004; Chen et al., 2003; Hinder et al., 2018; Ni et al., 2009). Generally, short-interval IHI is thought to be mediated via excitation of direct transcallosal inhibitory pathways to the contralateral M1, whereas long-interval IHI is thought to be mediated by indirect pathways, conceivably involving premotor regions in either hemisphere (Chen, 2004; Chen et al., 2003; Levin et al., 2014). In regard to the underlying IHI physiological processes, though mechanisms mediating short-interval IHI remain unclear, postsynaptic GABA_B receptors have been implicated in mediating long-interval IHI (Chen et al., 2003; Irlbacher et al., 2007). There is some evidence that SIHI and LIHI might be differently modulated during response preparation (Hinder et

al. 2018) and as a result of healthy ageing (Talelli et al., 2008), providing strong rationale for assessing both purported pathways in the current study.

2.4 Data processing

All catch trials (note that participants correctly withheld their response on 94.9% of such trials) and response omissions (an average of 1.5% of all trials requiring a response) were excluded from behavioural analyses. In addition, to preclude analysis of trials in which a 'true' choice process did not occur (e.g., participants responding to the warning signal or pre-empting the imperative signal; a 'fast guess'), additional constraints were imposed. Firstly, reaction times below 200 ms were discarded from further analyses. Secondly, cut-off reaction times were found for each participant and each bias type by using an exponentially-weighted moving average of accuracy (alpha parameter = 0.1; cut-off accuracy decision threshold = 0.6) after sorting by reaction time and discarding trials lower than this cut-off (Nunez et al., 2017; Vandekerckhove and Tuerlinckx, 2008). For accuracy data, errors were classified as trials on which an incorrect button press was recorded.

For neurophysiological measures, peak-to-peak MEP amplitude in the left and/or right FDI was determined in a 10-100 ms time window following TMS. For CSE trials, MEP amplitude was determined in the left and right FDI. For TMS trials conducted to assess SIHI and LIHI from the left to right M1, MEP amplitude was determined in the left FDI whereas for TMS trials conducted to assess SIHI and LIHI from the right to left M1, MEP amplitude was determined in the right FDI. Trials in which root mean square (rms) EMG activity exceeded 0.025 mV in a 50 ms time window immediately prior to the TMS pulse were excluded from inferential analyses due to the known effects of background EMG activity on MEP amplitude.

For all behavioural and neurophysiological measures, no data aggregation was conducted prior to inferential analyses (i.e., the inferential statistical model was conducted on trial level data). Moreover, even for conditioned TMS data (SIHI and LIHI), which generally requires the computation of the ratio between the average MEP amplitude elicited in conditioned trials to the average MEP amplitude evoked in unconditioned trials, the unique feature of the log-link function (i.e., back-transformation of estimates from the link to response scale resulting in ratios; Lo and Andrews, 2015) allowed us to avoid any data aggregation. That is, by utilising all MEP amplitudes from unconditioned and conditioned trials, SIHI and LIHI values can be determined using the back-transformation, with values less than 1 representing inhibitory interactions and values greater than 1 representing facilitatory interactions (Hinder et al., 2018).

2.5 Statistical procedures

For behavioural measures, Bayesian generalised linear mixed models (GLMMs) were utilised. Specifically, a GLMM with factors of AGE GROUP (Young, Older), BIAS TYPE (Block, Trial), and TRIAL TYPE (Congruent, Incongruent) was fit for accuracy (Bernoulli distribution with probit link) and reaction time on which an accurate response was recorded, i.e., 'correct reaction time', (shifted lognormal distribution with log link for the non-decision time parameter and an identity link for mu and sigma parameters; Cohen, 2018; De Boeck and Jeon, 2019) for data from

the behaviour only session. For correct reaction time data, the non-decision time shift parameter (*ndt*), reflecting the time taken for stimulus encoding and response production processes, as well as the median of the shifted lognormal distribution, reflecting the sum of non-decision and decision processes – were analysed. For the accuracy analysis, the proportion of correct responses is reported.

For neurophysiological measures, Bayesian GLMMs with a Gamma distribution (and log link function) – appropriate for non-negative, positively skewed, data such as MEP amplitude – were utilised. To assess the effect of *task context*, neurophysiological measures at the first baseline block (i.e., out-of-task context prior to any task manipulations) were compared to neurophysiological measures at WS (i.e., in-task context but before any movement preparation and execution processes were elicited). Specifically, for CSE, SIHI and LIHI, separate GLMMs with factors of AGE GROUP (Young, Older), HAND (Left, Right), and COND (Baseline, WS_{block-wise}, WS_{trial-wise}) were fit with the additional factor of TMS TYPE (Unconditioned, Conditioned) for SIHI and LIHI analyses.

To assess movement *preparation* related processing, neurophysiological measures at WS, Fixation, and IS were considered (i.e., prior to response generation) with the hand being biased either towards or away from the IS (see hand status in Figure 1: T and A) at each of the time-points except for the WS (as no WS-related processing had occurred). Thus, for CSE, SIHI, and LIHI, separate GLMMs with factors of AGE GROUP (Young, Older), BIAS TYPE (Block, Trial), COND (WS_{Neither}, Fixation_T, Fixation_A, IS_T, IS_A) were fit with the additional factor of TMS TYPE (Unconditioned, Conditioned) for SIHI and LIHI analyses.

To assess movement *execution* related processing, neurophysiological measures at IS and IS100 were considered, only on correct response trials, with the hand not only being biased (i.e., towards vs. away) but also responding or not responding to the IS at IS100 (see hand status in Figure 1: R and NR) but not at IS (as no IS-related processing had occurred). Thus, for CSE, SIHI, and LIHI, separate GLMMs with factors of AGE GROUP (Young, Older), BIAS TYPE (Block, Trial), COND (IS_T, IS_A, IS100_{T_R}, IS100_{A_R}, IS100_{T_NR}, IS100_{A_NR}) were fit with the additional factor of TMS TYPE (Unconditioned, Conditioned) for SIHI and LIHI analyses. For all neurophysiological analyses, only main and interaction effects involving COND are reported, as these effects capture the task-related and cue-related changes of interest. Specifically, our analyses are focussed on understanding how neurophysiological mechanisms can be regulated by biasing information to prepare and execute movements. Thus, we are primarily interested in the main effect of COND as well as how it interacts with healthy ageing (i.e., AGE GROUP x COND) and bias type (i.e., COND x BIAS TYPE). In contrast, the main effects of AGE GROUP and BIAS TYPE do not capture how participants regulate neurophysiological mechanisms on the basis of the biasing cue, and are not the focus of the current study.

Following model fitting, specific contrasts were conducted to probe main and interaction effects. To this end, the posterior distribution was utilised to obtain indices of effect *existence* (i.e., consistency of an effect in one particular direction – either positive or negative) and *significance* (i.e., magnitude of the effect) (Makowski et al., 2019b). For effect existence, the probability of direction (*pd*) – defined as the

463 proportion of the posterior distribution that is of the median's sign – is reported as a
464 percentage value, varying from 50-100%. The 'consistency' of an effect is defined
465 along a continuum between a theoretically most *inconsistent* *pd* value of 50%, to a
466 theoretically most consistent *pd* values of 100%. For evaluation purposes, the *pd* has
467 an almost 1:1 relationship with the frequentist *p*-value, with a *pd* of 97.5%
468 corresponding to a two-sided frequentist *p*-value of 0.05 (Makowski et al., 2019b).
469 For effect significance, first, a "region of practical equivalence" (ROPE) – a range of
470 values close to zero that are *practically equivalent* to zero (i.e., of negligible
471 magnitude) – was defined for models using the probit link (task accuracy: $\pm 2\%$) and
472 log link (correct reaction time and neurophysiological measures: $\pm 5\%$). These user-
473 defined ROPE limits were chosen as we consider in this particular simple decision-
474 making task that a small difference in accuracy is likely to be more meaningful than a
475 similar-sized difference in RT or neurophysiological measures. Second, for each
476 main and interaction effect, an 89% highest density interval (HDI) – range within
477 which 89% of the posterior distribution lies – was defined. Using the HDI and ROPE,
478 the percentage of HDI falling within the ROPE is reported (*% of HDI in ROPE*).
479 Though this value is interpretable in itself, the "HDI+ROPE" decision rule (Kruschke,
480 2018) is also utilised such that a) if the 89% HDI falls completely inside the ROPE,
481 *the null hypothesis of no difference (H_0) is accepted*, b) if the 89% HDI falls
482 completely outside the ROPE, *the null hypothesis is rejected*, and c) if the 89% HDI
483 does not fall completely inside or outside the ROPE, *no decision regarding the null*
484 *hypothesis is reached*.

485
486 Posterior distributions for all models – run using four independent chains, each with
487 1500 warm up and 1500 post-warm up samples (6000 total post-warm up samples)
488 – were obtained using the NUTS extension of Hamiltonian Monte Carlo. Improper flat
489 priors over real values were used for population-level parameters. The 'adapt delta'
490 value was increased as necessary to ensure convergence of chains which was
491 assessed visually by inspecting plots of post-warm up samples as well as ensuring
492 that the potential scale reduction factor on split chains (Rhat) was < 1.1 (Gelman and
493 Rubin, 1992). Visual posterior predictive checks were conducted, comparing
494 observed and simulated data, to ensure models reproduced the observed data
495 (Gabry et al., 2019). In addition, the maximal random effect structure (i.e., by-
496 participant random intercepts and by-participant random slopes for all fixed effects
497 as well as correlations among random effects, separately for young and older age
498 groups) as justified by the design and allowed by the data was specified for every
499 model (Barr, 2013; Singmann and Kellen, 2019). All statistical analyses and
500 graphical outputs were generated in R version 4.0.2 (R Core Team 2020), via
501 RStudio version 1.3.959 (RStudio Team 2020), using the 'here' (Kiril Müller 2020),
502 'tidyverse' (Wickham et al., 2019), 'brms' (Bürkner, 2017), 'emmeans' (Lenth 2021),
503 'insight' (Lüdtke et al., 2019), 'bayestestR' (Makowski et al., 2019a), and
504 'patchwork' (Pedersen 2020) packages with default settings, unless specified above.
505 All data are available via <https://osf.io/9mbez>.

3. Results

All data are reported with medians and the 89% HDI in square brackets, unless specified otherwise.

3.1 Behavioural effects

For one participant two blocks of data could not be collected.

3.1.1 Accuracy

Participants were more accurate on congruent (99.1% [98.9 – 99.4]) than incongruent (96.4% [95.5 – 97.3]) trials, as illustrated in Figure 2a, with this difference (2.8% [2.1 – 3.6]) being both consistent ($pd = 100\%$) and significant as the null hypothesis was rejected (0% in ROPE).

Comparing the two different age groups there was a consistent ($pd = 93.4\%$), but negligible (0.9% [-0.1 – 1.8]), difference between older (98.5% [98.0 – 99.1]) and young (97.7% [96.9 – 98.4]) adults, with the null hypothesis being supported (100% in ROPE). Similarly, there was a negligible (0.03% [-0.3 – 0.4]) and non-existent ($pd = 55.6\%$) difference between the block-wise (98.2% [97.6 – 98.6]) and trial-wise (98.1% [97.7 – 98.6]) bias types, with the null hypothesis being supported (100% in ROPE). Lastly, the data provided support for the null hypothesis for all three two-way interaction effects as well as the three-way interaction effect (i.e., for all effects, 100% in ROPE) with $pds < 82.4\%$.

Overall, participants were consistently and significantly more accurate on congruent than incongruent trials.

3.1.2 Correct reaction time

Older adults (393 ms [375 – 412]) were 26.5% [17.3 – 37.3] slower than young adults (311 ms [297 – 323]), as illustrated in Figure 2b, with this difference being both consistent ($pd = 100\%$) and significant as the null hypothesis was rejected (0% in ROPE). The same pattern was observed for the *ndt* parameter too, with older adults (179 ms [170 – 187]) exhibiting longer non-decision time than young adults (167 ms [159 – 174]) and though this effect was consistent ($pd = 96.3\%$), it was not significant (29.0% in ROPE).

Participants were 12.4% [11.9 – 13.0] slower on incongruent (373 ms [360 – 385]) than congruent (331 ms [321 – 342]) trials with this difference being consistent ($pd = 100\%$) and significant as the null hypothesis was rejected (0% in ROPE). This slowing was observed for the *ndt* parameter too as longer non-decision time was observed for incongruent (177 ms [170 – 183]) than congruent (169 ms [125 – 141]) trials. However, though this effect was consistent ($pd = 100\%$), it was not significant (80.5% in ROPE). Lastly, for all other main and interaction effects, the data provided support for the null hypothesis (> 94.4% in ROPE; pds ranging from 60 – 100%).

Overall, older participants exhibited slower correct reaction time compared to younger adults. For all adults, correct reaction time was slower during incongruent, than congruent, trials. This pattern of results for age group and trial type were also observed (albeit insignificantly) when considering non-decision time.

Figure 2 – Behavioural measures. Boxplots depict, on the ordinate, a) the observed proportion of correct responses, and b) the observed correct reaction time (in milliseconds), for young (dashed) and older (solid) adults for both bias types (unfilled: block-wise bias; filled: trial-wise bias) and both trial types (congruent and incongruent) on the abscissa. Carat (^) and exclamation (!) symbols denote practically significant trial type and aging effects, respectively. Lower and upper hinges depict the 25th and 75th percentile respectively with the lower and upper whiskers depicting values 1.5 * interquartile range (IQR defined as distance between 25th and 75th percentile) below and above the hinges, respectively. Data beyond the whiskers are plotted as filled circles.

3.2 Neurophysiological effects

Five participants' (two and three from the older and young groups, respectively) neurophysiological data could be not collected due to various reasons. Three were unable to participate or complete the combined session and technical difficulties affected the other two participants' session. In addition, one younger participant's out-of-task baseline TMS data could not be collected due to technical difficulties.

For the different TMS trial types administered to ascertain CSE, SIHI, and LIHI at the different TMS time-points (out-of-task baseline, WS, Fixation, IS, and IS100), mean (range: 5.9 to 7.5 μ V) and standard deviation (range: 3.8 to 5.1 μ V) of rms EMG values indicated that participants' muscle activity was quiescent with no substantial differences between TMS trial type and time-points.

Lastly, correlation analyses between practically significant bias-specific neurophysiological changes and behavioural measures are not included (or interpreted) within the main body of the paper, because correlations conducted on averaged data may be associated with reduced power and the possibility of misleading results (Bakdash and Marusich, 2017). However, at the request of the editor and an anonymous reviewer, correlations are presented in the supplementary material (Figure S1) for the interested reader. In addition, figures of results that were not of practical significance or inconclusive are not plotted but the interested reader is guided to these figures in the supplementary material (Figures S2-S4).

3.2.1 Task context

For CSE, in-task baseline exhibited consistent (all $pds = 100\%$) and significant (all 0% in ROPE) increases compared to out-of-task baseline, as illustrated in Figure 3a. Specifically, CSE was 77.8% [57.9 – 100.3] and 78.7% [58.1 – 103.2] greater for block-wise (2.24 mV [1.89 – 2.61]) and trial-wise (2.25 mV [1.84 – 2.64]) conditions, respectively, compared to out-of-task resting baseline (1.26 mV [1.05 – 1.49]). Furthermore, there was not enough evidence to accept or reject the null hypothesis for differences between the block-wise and trial-wise conditions (63.3% in ROPE), with these differences being inconsistent ($pd = 53.5\%$). Similarly, there was not enough evidence to accept or reject the null hypothesis for interaction effects involving COND (19.1% - 55.3% in ROPE) with $pds < 93.2\%$.

For SIHI, in-task baseline exhibited consistent (all $pds > 99.8\%$) and significant (all 0% in ROPE) reduction in inhibition compared to out-of-task resting baseline as depicted in Figure 3b. Specifically, SIHI was reduced by 20.8% [13.6 – 27.9] and 17.3% [9.1 – 25.4] for block-wise (0.66 [0.58 – 0.74]) and trial-wise (0.63 [0.56 – 0.70]) bias conditions, respectively, compared to out-of-task baseline SIHI (0.52 [0.46 – 0.59]). Furthermore, there was not enough evidence to accept or reject the null hypothesis for differences between the block-wise and trial-wise conditions (55.7% in ROPE; $pd = 77.0\%$). Lastly, there was not enough evidence to accept or reject the null hypothesis for interaction effects involving COND (12.3% - 39.8% in ROPE) with $pds < 93.0\%$.

For LIHI, there was not enough evidence to accept or reject the null hypothesis for any effect involving COND (12.2% – 68.4% in ROPE) with $pds < 87.9\%$.

618
619 Overall, greater CSE and SIHI attenuation were observed as a result of general,
620 task-related, cognitive processing.

Figure 3 – Task context. Boxplots depict, on the ordinate, a) CSE (in mV), and b) SIHI ratio, for an out-of-task baseline ("Baseline") as well as the first, in-task, time-point for both block-wise ("Block-wise WS") and trial-wise ("Trial-wise WS") conditions, plotted on the abscissa. Hash (#) and dollar (\$) symbols denote practically significant effects for CSE and SIHI, respectively. Lower and upper hinges depict the 25th and 75th percentile, respectively, with the lower and upper whiskers depicting values 1.5 * interquartile range (IQR defined as distance between the two hinges) below and above the hinges, respectively. Data beyond the whiskers are plotted as filled circles.

3.2.2 Movement preparation

For CSE, evidence of preparatory inhibition was observed as consistent (all $pds = 100\%$) and significant (all 0% in ROPE) reductions in CSE at IS relative to CSE at the start of (i.e., at WS) and halfway through (i.e., at fixation) the preparatory period. Such reductions occurred regardless of whether the hand was biased towards or away from the WS (Fig 4a). Specifically, for the hand biased towards the WS, CSE at IS (1.86 mV [1.58 – 2.16]) was 19.7% [13.7 – 25.5] and 16.8% [10.2 – 23.2] lower than CSE at WS (2.32 mV [2.00 – 2.69]) and fixation (2.24 mV [1.91 – 2.58]), respectively. For the hand biased away from the WS, CSE at IS (1.76 mV [1.48 – 2.06]) was 24.1% [18.5 – 29.8] and 20.1% [13.8 – 26.2] lower than CSE at WS (2.32 mV [2.00 – 2.69]) and fixation (2.20 mV [1.87 – 2.53]), respectively. Though similar reductions were observed comparing CSE at fixation with CSE at WS (all $pds > 91.0\%$), these reductions were of negligible magnitude (74.9% and 49.9% in ROPE for the hand biased toward and away from the WS, respectively). Lastly, there was not enough evidence to accept or reject the null hypothesis for interaction effects involving COND (25.6% – 77.7% in ROPE) with $pds < 92.2\%$.

For SIHI, a consistent (all $pds > 99.7\%$) and significant (all 0% in ROPE) reduction was observed at IS in the hand biased towards the WS relative to SIHI at the start of and halfway through the preparatory period, suggesting an influence of response bias on SIHI (Fig 4b). Specifically, for the hand biased towards the WS, SIHI at IS (0.79 [0.71 – 0.87]) was 19.1% [9.6 – 28.3] and 16.3% [6.4 – 27.3] lower than SIHI at WS (0.66 [0.61 – 0.72]) and fixation (0.68 [0.62 – 0.75]), respectively. Interestingly, this reduction of SIHI at IS in the hand biased towards the WS was 11.5% greater (1.7 – 21.6) than SIHI at IS in the hand biased away from the WS (0.71 [0.64 – 0.78]), and though this was a consistent effect ($pd = 97.5\%$), it was not of a practically relevant magnitude (11.3% in ROPE). Lastly, there was not enough evidence to accept or reject the null hypothesis for other effects (6.03% – 52.9% in ROPE) with $pds < 96.6\%$.

For LIHI, a consistent (all $pds = 100\%$) and significant (all 0% in ROPE) reduction was observed at IS relative to LIHI at the start of, and halfway through, the preparatory period, regardless of whether the hand was biased towards or away from the WS (Fig 4c). Specifically, for the hand biased towards the WS, LIHI at IS (0.93 [0.86 – 1.00]) was 26.7% [18.5 – 34.3] and 20.4% [12.0 – 29.8] lower than LIHI at WS (0.73 [0.69 – 0.78]) and fixation (0.77 [0.72 – 0.83]), respectively. For the hand biased away from the WS, LIHI at IS (0.93 [0.86 – 1.01]) was 27.3% [19.4 – 35.1] and 20.1% [10.8 – 28.7] lower than LIHI at WS (0.73 [0.69 – 0.78]) and fixation (0.78 [0.72 – 0.84]), respectively. Furthermore, the reduction of LIHI at IS for the hand biased away from the WS was consistently (all $pds > 98.8$) and significantly ($< 0.9\%$ in ROPE) modulated by bias type such that greater LIHI reductions were observed for trial-wise bias, where the WS changed from trial-to-trial, than for block-wise bias, where the WS remained unchanged for the whole block. Specifically, the reduction of LIHI at IS in the hand biased away from the WS, relative to LIHI at WS and even LIHI at IS in the hand biased towards the WS, was 19.0% [6.2 – 32.9] and 21.1% [4.3 – 37.5] greater for trial- than block-wise bias. Lastly, there was not enough evidence to accept or reject the null hypothesis for interaction effects involving COND (10.5% – 55.4% in ROPE) with $pds < 94.2\%$.

681 Overall, when response preparation was maximal, CSE decreases and LIHI
682 reductions were observed regardless of response bias. Some specificity of IHI
683 mechanisms was observed as SIHI reduction was greater in the hand biased *towards*
684 the WS and LIHI reduction was greater in the hand biased *away* from the WS when
685 the most likely response option changed trial-to-trial.

Figure 4 – Movement preparation. Boxplots depict, on the ordinate, a) CSE (in mV), b) SIHI ratio, and c) LIHI ratio at WS, Fixation, and IS time-points on the abscissa. These data are plotted for when the hand is biased towards (unfilled) and away (light grey) from the WS as well as when no hand bias is possible (dark grey; i.e., at WS). In addition, only for LIHI, the two bias types – block-wise (dashed) and trial-wise (dotted) – are plotted separately. Hash (#), dollar (\$), and ampersand (&) symbols denote practically significant effects for CSE, SIHI, and LIHI, respectively. Lower and upper hinges depict the 25th and 75th percentile respectively with the lower and upper whiskers depicting values 1.5 * interquartile range (IQR defined as distance between the two hinges) below and above the hinges, respectively. Data beyond the whiskers are plotted as filled circles.

3.2.3 Movement execution

For CSE, at IS100, response bias effects were observed as CSE in the hand biased away from the WS, compared to CSE in the hand biased *towards* the WS, was 8.00% [1.5 – 14.5] and 9.50% [3.6 – 15.5] lower in the responding and non-responding hand, respectively (Figure 5a). Though these were consistent effects (responding hand $pd = 97.1\%$; non-responding hand $pd = 99.3\%$) they were *not* of sufficient practical magnitude (responding hand ROPE = 19.9%; non-responding hand ROPE = 5.4%). For all other CSE effects involving COND, there was not enough evidence to accept or reject the null hypothesis (17.9% – 89.9% in ROPE) with $pds < 91.3\%$.

For SIHI, at IS100, consistent ($pd = 98.8\%$) and relatively significant (3.7% in ROPE) movement execution related processing was observed as SIHI was 11.8% [1.7 – 20.9] greater in the non-responding (0.72 [0.65 – 0.78]) compared to responding (0.82 [0.75 – 0.88]) hand when the hand was biased towards the WS, as observed in Figure 5b. For all other SIHI effects, there was not enough evidence to accept or reject the null hypothesis for any effect involving COND (13.5% – 68.5% in ROPE) with $pds < 97.1\%$.

For LIHI, there was not enough evidence to accept or reject the null hypothesis for any effect involving COND (5.3% – 75.9% in ROPE) with $pds < 96.6\%$.

Overall, to facilitate response execution, greater SIHI was observed 100 ms after the IS when the biased hand was not responding compared to when it was responding.

Figure 5 – Movement execution. Boxplots depict, on the ordinate, a) CSE (in mV), and b) SIHI ratio at IS and IS100 time-points on the abscissa. These are plotted for all combinations of when the hand is biased towards (solid) and away (dashed) from the WS, and when it is not responding (unfilled), responding (light grey), or neither i.e., prior to processing the IS (dark grey). Dollar (\$) symbol denotes practically significant effect for SIHI. Lower and upper hinges depict the 25th and 75th percentile respectively with the lower and upper depicting values 1.5 * interquartile range (IQR defined as distance between the two hinges) below and above the hinges, respectively. Data beyond the whiskers are plotted as filled circles.

4. Discussion

The current study provides novel insights into the behavioural and neurophysiological effects of response bias across the lifespan. Participants were required to make fast-as-possible response to choice stimuli which were preceded by a cue that informed them that either stimulus was 70% likely. Participants responded more quickly, and more accurately, on trials in which the imperative stimulus was congruent, compared to incongruent, with the cue. Consistent with previous research, reductions in CSE were observed bilaterally during movement preparation, suggestive of an impulse control mechanism. However, inhibitory interhemispheric M1 networks were modulated in opposite directions as a function of response bias, suggestive of a competition resolution mechanism. Specifically, less SIHI was observed during movement preparation in the hand biased towards, compared to the hand biased away from, the warning cue. Additionally, the LIHI ratio of the hand biased away from, compared to the hand biased towards, the warning cue during movement preparation was greatest when cues varied trial-by-trial compared to when cues were consistent. Lastly, during movement *execution*, reduced SIHI was observed in the biased hand when it was responding than when it was not.

4.1 Behavioural effects

Participants were more accurate and quicker to respond on congruent, than incongruent, trials, in line with broader research where participants are provided prior information of upcoming task demands (Bestmann et al., 2008; Garton et al., 2019; Hasbroucq et al., 1999; Hinder et al., 2018; Mars et al., 2007; Sinclair and Hammond, 2009). From a response bias perspective, our reaction-time results add further evidence to the notion of participants successfully *weighting* prior biasing information. Specifically, this quickening of reaction times on congruent, than incongruent, trials *increases* with increasing response bias. Differences of ~ 10 – 20 ms (Fig S1A in Bestmann et al., 2008), ~ 40 – 50 ms (Fig S1A in Bestmann et al., 2008; Garton et al., 2019; current study), and ~ 80 – 100 ms (Fig S1A in Bestmann et al., 2008) are observed with biasing cues of 55 – 45 %, 70 – 30 %, and 85 – 15%, respectively.

In regard to the biasing procedures, an absence of a significant difference in accuracy and correct reaction time was observed between block- and trial-wise biasing procedures. This result is in line with another recent study (Garton et al., 2019) and suggests effective cognitive flexibility as participants are able to utilise response biasing information not only as cues are consistent across the whole block but, more importantly, also when cues change from trial-to-trial.

The vast majority of studies in this research field rely upon central tendencies (e.g., mean, median) to compare reaction times between various conditions. Here, trial wise data (i.e., the use of the whole reaction-time distribution, via the shifted lognormal distribution), allowed additional insights into the effects of response bias. Of interest, we found that *non-decision time* was greater in older (compared to younger) adults and on incongruent (compared to congruent) trials, suggesting that the overall slowing was not only based on decision-making processes but also on non-decision processes such as stimulus encoding and response production. These

results are in line with research utilizing more computationally intensive ‘evidence accumulation models’ such as the drift diffusion model (Ratcliff and McKoon, 2008) and the linear ballistic accumulator model (Brown and Heathcote, 2008), both for the incongruency (Starns and Ma, 2018; Voss et al., 2010) and ageing (Dully et al., 2018; Theisen et al., 2020; von Krause et al., 2020) effects. It is important to note that although both these effects were consistent ($pd > 96\%$), they were not significant considering the bounds of practical equivalence utilised in the current study.

4.2 Neurophysiological effects

4.2.1 Task- context

In line with previous research, we observed significantly greater CSE during the in-task baseline compared to an out-of-task resting baseline (Duque et al., 2016; Klein et al., 2014; Labruna et al., 2010; Quoilin et al., 2019; Vassiliadis et al., 2018). This generic CSE increase (i.e., in all hands in all bias-type conditions) compared to an out-of-task baseline, most likely reflects arousal and attention processes related to movement preparation. However, no inferences can be made as to the origins of this change in CSE because MEP amplitude from unconditioned TMS is a summed output of direct and indirect (via intra-, inter-, and sub-cortical inputs) activation of the corticospinal motoneurons (Bestmann and Krakauer, 2015). However, the conditioned TMS trials enable us to provide novel evidence to indicate CSE increases were driven by, at least in part, reductions in SIHI. That is, significant attenuation of SIHI was observed during the in-task baseline compared to the out-of-task resting baseline, possibly reflecting generic movement-related preparation.

4.2.2 Movement preparation

One of most prominent and reliable findings in the movement preparation literature is the reduction in CSE, with this decrease being the strongest just prior to the onset of the imperative cue (for comprehensive reviews see Bestmann and Duque, 2016; Derosiere and Duque, 2020). Various hypotheses regarding the role of this ‘preparatory inhibition’ have been put forward (see Duque et al., 2017 for a comprehensive review). ‘Inhibition for competition resolution’ suggests that the inhibition observed in non-selected effectors aims to facilitate action selection by ensuring the ‘winner takes all’. Indeed, in the context of a choice reaction-time task, greater CSE suppression is often observed in the non-selected effector compared to the selected effector. However, the observation of CSE suppression in the selected effector as well as task-irrelevant effectors poses a challenge for this hypothesis and led to the formulation of the ‘inhibition for impulse control’ hypothesis. This hypothesis suggests that the observed widespread inhibition serves to prevent the release of all action representations, as evidence is gathered to select the most appropriate representation, until a cue dictates the initiation of the selected action (i.e., to prevent premature movements).

In the current study, significant reductions in CSE were observed at the end of, relative to the start and halfway through, the preparatory period. This reduction was observed in the hand biased towards the WS as well as the hand biased away from the WS, highlighting the generic nature of the CSE reductions. These results are in

line with previous research and provide further evidence for the ‘inhibition for impulse control’ hypothesis (Greenhouse et al., 2015; Hasbroucq et al., 1997; Thierry Hasbroucq et al., 1999; Hinder et al., 2018; Ibáñez et al., 2020; Lebon et al., 2016; Tandonnet et al., 2010; Vassiliadis et al., 2018). However, IHI changes in both hands during the preparatory period highlight a more specific role for the putatively GABAergic M1 interhemispheric inhibitory networks. Specifically, at the end of the preparatory period, SIHI in the hand biased away from the WS was significantly greater than SIHI in the hand biased towards the WS. This suggests a clear effect of response bias on SIHI networks subserving movement preparation, most likely via direct transcallosal pathways. Furthermore, significantly less LIHI was observed at the end of the preparatory period in the hand biased away from, compared to towards, the WS with this LIHI reduction greater during the trial-wise bias procedure compared to the block-wise bias procedure. The fact that the most probable response could change from trial-to-trial in the trial-wise bias procedure (compared to the most probable response remaining consistent for the block-wise bias procedure), likely made the trial-wise condition more cognitively demanding. As such LIHI networks that are thought to be mediated by more (pre)frontal regions and influenced by top-down processes (Hinder et al., 2018; Ni et al., 2009) may have played a more critical role. Overall, these results highlight the opposing manner in which IHI networks are modulated depending on the direction of the connectivity and the likely involvement of an effector in the upcoming movement preparation, consistent with the ‘inhibition for competition resolution’ hypothesis (for a review see Duque et al., 2017). To our knowledge, this is the first study to highlight the involvement of these M1 interhemispheric inhibitory networks to this end.

4.2.3 Movement execution

Previous research investigating neural changes during the movement execution period (i.e., post-IS) provide support for the ‘inhibition for competition resolution’ hypothesis whereby CSE is suppressed in the non-responding effector and facilitated in the responding effector (Duque et al., 2014; Hinder et al., 2018; Klein et al., 2016). However, in the current study, no such effects were observed. This is most likely related to the specific time-point at which CSE was measured (i.e., 100 ms post-IS) or the nature of the WS; indeed such bidirectional changes have been observed closer to movement execution (Duque et al., 2014; Klein et al., 2016) or when the WS provides unambiguous information about the upcoming IS (Hinder et al., 2018), as opposed to the biasing/likelihood information provided in the current study.

In contrast to CSE, SIHI *did* capture movement execution related effects. Specifically, SIHI was greater in the non-responding, compared to the responding, hand, assisting movement execution by suppressing the non-responding effector and facilitating, via release of inhibition, the responding effector. Of particular interest, this result was only observed in the hand biased towards the WS, suggesting an influence of response bias. Given that reaction times were slower on incongruent trials, it is conceivable that a similar pattern would be observed in the hand biased away from the WS at a later time-point than that measured here (i.e., more than 100 ms post-IS). Previous research in humans has implicated SIHI mechanisms during movement execution (Hinder et al., 2018; Liuzzi et al., 2010). However, IHI measures were only assessed in one hand with the nature of the task

(choice RT) specifying 'responding' and 'non-responding' hand status, leading to equivocal evidence regarding the nature of SIHI as effects may be confounded due to hand dominance. The current study extends previous research and provides more direct evidence for the role of SIHI not only in movement execution more broadly but also as a neural mechanism subserving the 'inhibition for competition resolution' hypothesis.

5. Future directions and conclusions

The insights from the current research may be built upon in numerous ways, some of which are considered below. First, the neurophysiological data in the current study did not provide enough evidence to accept or reject the null hypothesis for all the age effects related to movement preparation and execution; future research should therefore consider larger sample sizes to investigate this important aspect. Second, it would be of interest to conduct future research in clinical groups that exhibit deficits in movement preparation such as focal hand dystonia (Beck et al., 2008), stroke (Hummel et al., 2009), and alcohol dependence (Quoilin et al., 2018) to name a few. Third, besides the M1 interhemispheric inhibitory networks implicated in the current study, movement preparation is known to be subserved by other connections between M1 and cortical areas such as the premotor and prefrontal cortex (Duque et al., 2012), M1 *intracortical* inhibitory networks (Duque and Ivry, 2009; Gomez et al., 2021; Sinclair and Hammond, 2008; Tandonnet et al., 2010), excitatory projections to M1 (Hannah et al., 2017), and spinal excitability (Duque et al., 2010). Hence, it would be important to consider their contributions on biased movement preparation. Fourth, future research should consider not only the extent of inhibition exerted by IHI networks by probing task-*irrelevant* muscles too but also the temporal nuances involved by taking neurophysiological measures at multiple time-points during the movement preparation and execution period.

In conclusion, the current study investigated, in groups of healthy young and older adults, the behavioural and neurophysiological effects of response bias. From a behavioural perspective, participants responded more quickly and accurately on congruent, compared to incongruent, trials. From a neurophysiological perspective, widespread CSE reductions were observed during movement preparation that provided support for the 'inhibition for impulse control' hypothesis. In contrast, the modulation of inhibitory interhemispheric M1 networks provided support for the 'inhibition for competition resolution' hypothesis. Specifically, reduced SIHI was observed not only during movement preparation in the hand biased towards, than away from, the preparatory cue but also during movement execution in the hand biased towards the preparatory cue when it was responding compared to when it was not. In addition, during movement preparation the LIHI ratio of the hand biased towards, than away, from the cue was greatest when the cues varied trial-by-trial. Overall, these results suggest a crucial role of IHI networks in movement preparation and execution.

927 **Acknowledgements**

928

929 RP was supported by an Australian Government Research Training Program (RTP)
930 Scholarship. MRH was supported by the Australian Research Council's Future
931 Fellowship (FT150101406) funding scheme. In addition, this research was
932 undertaken with the assistance of resources from the TERN CoESRA Virtual
933 Desktop. Lastly, we would like to sincerely thank Tess Nikitenko for assistance with
934 data collection as well as all the participants for contributing their valuable time.

References

- Bakdash, J.Z., Marusich, L.R., 2017. Repeated measures correlation. *Front. Psychol.* 8, 456. <https://doi.org/10.3389/FPSYG.2017.00456/BIBTEX>
- Barr, D.J., 2013. Random effects structure for testing interactions in linear mixed-effects models. *Front. Psychol.* 4. <https://doi.org/10.3389/fpsyg.2013.00328>
- Beck, S., Richardson, S.P., Shamim, E.A., Dang, N., Schubert, M., Hallett, M., 2008. Short intracortical and surround inhibition are selectively reduced during movement initiation in focal hand dystonia. *J. Neurosci.* 28, 10363–10369. <https://doi.org/10.1523/JNEUROSCI.3564-08.2008>
- Bestmann, S., Duque, J., 2016. Transcranial Magnetic Stimulation: Decomposing the Processes Underlying Action Preparation. *Neuroscientist* 22, 392–405. <https://doi.org/10.1177/1073858415592594>
- Bestmann, S., Harrison, L.M., Blankenburg, F., Mars, R.B., Haggard, P., Friston, K.J., Rothwell, J.C., 2008. Influence of Uncertainty and Surprise on Human Corticospinal Excitability during Preparation for Action. *Curr. Biol.* 18, 775–780. <https://doi.org/10.1016/j.cub.2008.04.051>
- Bestmann, S., Krakauer, J.W., 2015. The uses and interpretations of the motor-evoked potential for understanding behaviour. *Exp. Brain Res.* <https://doi.org/10.1007/s00221-014-4183-7>
- Brown, S.D., Heathcote, A., 2008. The simplest complete model of choice response time: Linear ballistic accumulation. *Cogn. Psychol.* 57, 153–178. <https://doi.org/10.1016/j.cogpsych.2007.12.002>
- Bundt, C., Abrahamse, E.L., Braem, S., Brass, M., Notebaert, W., 2016. Reward anticipation modulates primary motor cortex excitability during task preparation. *Neuroimage* 142, 483–488. <https://doi.org/10.1016/j.neuroimage.2016.07.013>
- Bundt, C., Bardi, L., Verbruggen, F., Boehler, C.N., Brass, M., Notebaert, W., 2019. Reward anticipation changes corticospinal excitability during task preparation depending on response requirements and time pressure. *Cortex.* <https://doi.org/10.1016/j.cortex.2019.05.020>
- Bürkner, P.C., 2017. brms: An R package for Bayesian multilevel models using Stan. *J. Stat. Softw.* 80. <https://doi.org/10.18637/jss.v080.i01>
- Chen, R., 2004. Interactions between inhibitory and excitatory circuits in the human motor cortex. *Exp. Brain Res.* <https://doi.org/10.1007/s00221-003-1684-1>
- Chen, R., Yung, D., Li, J.Y., 2003. Organization of ipsilateral excitatory and inhibitory pathways in the human motor cortex. *J. Neurophysiol.* 89, 1256–1264. <https://doi.org/10.1152/jn.00950.2002>
- Cisek, P., 2007. Cortical mechanisms of action selection: The affordance competition hypothesis. *Philos. Trans. R. Soc. B Biol. Sci.* 362, 1585–1599. <https://doi.org/10.1098/rstb.2007.2054>
- Cohen, A.C., 2018. Three-Parameter Estimation, in: *Lognormal Distributions*. Routledge, pp. 113–137. <https://doi.org/10.1201/9780203748664-4>
- De Boeck, P., Jeon, M., 2019. An overview of models for response times and processes in cognitive tests. *Front. Psychol.* <https://doi.org/10.3389/fpsyg.2019.00102>
- Derosiere, G., Duque, J., 2020. Tuning the Corticospinal System: How Distributed Brain Circuits Shape Human Actions. *Neurosci.* 107385841989675. <https://doi.org/10.1177/1073858419896751>
- Derosiere, G., Vassiliadis, P., Duque, J., 2020. Advanced TMS approaches to probe corticospinal excitability during action preparation. *Neuroimage* 116746.

985 <https://doi.org/10.1016/j.neuroimage.2020.116746>
 986 Dick, J.P., Guiloff, R.J., Stewart, A., Blackstock, J., Bielawska, C., Paul, E.A.,
 987 Marsden, C.D., 1984. Mini-mental state examination in neurological patients. *J.*
 988 *Neurol. Neurosurg. Psychiatry* 47, 496–499.
 989 <https://doi.org/10.1136/jnnp.47.5.496>
 990 Dully, J., McGovern, D.P., O'Connell, R.G., 2018. The impact of natural aging on
 991 computational and neural indices of perceptual decision making: A review.
 992 *Behav. Brain Res.* <https://doi.org/10.1016/j.bbr.2018.02.001>
 993 Duque, J., Greenhouse, I., Labruna, L., Ivry, R.B., 2017. Physiological Markers of
 994 Motor Inhibition during Human Behavior. *Trends Neurosci.* 40, 219–236.
 995 <https://doi.org/10.1016/j.tins.2017.02.006>
 996 Duque, J., Ivry, R.B., 2009. Role of corticospinal suppression during motor
 997 preparation. *Cereb. Cortex* 19, 2013–2024.
 998 <https://doi.org/10.1093/cercor/bhn230>
 999 Duque, J., Labruna, L., Cazaes, C., Ivry, R.B., 2014. Dissociating the influence of
 1000 response selection and task anticipation on corticospinal suppression during
 1001 response preparation. *Neuropsychologia* 65, 287–296.
 1002 <https://doi.org/10.1016/j.neuropsychologia.2014.08.006>
 1003 Duque, J., Labruna, L., Verset, S., Olivier, E., Ivry, R.B., 2012. Dissociating the Role
 1004 of Prefrontal and Premotor Cortices in Controlling Inhibitory Mechanisms during
 1005 Motor Preparation. *J. Neurosci.* 32, 806–816.
 1006 <https://doi.org/10.1523/JNEUROSCI.4299-12.2012>
 1007 Duque, J., Lew, D., Mazzocchio, R., Olivier, E., Ivry, R.B., 2010. Evidence for Two
 1008 Concurrent Inhibitory Mechanisms during Response Preparation. *J. Neurosci.*
 1009 30, 3793–3802. <https://doi.org/10.1523/JNEUROSCI.5722-09.2010>
 1010 Duque, J., Petitjean, C., Swinnen, S.P., 2016. Effect of aging on motor inhibition
 1011 during action preparation under sensory conflict. *Front. Aging Neurosci.* 8, 1–14.
 1012 <https://doi.org/10.3389/fnagi.2016.00322>
 1013 Ferbert, A., Priori, A., Rothwell, J.C., Day, B.L., Colebatch, J.G., Marsden, C.D.,
 1014 1992. Interhemispheric inhibition of the human motor cortex. *J. Physiol.* 453,
 1015 525–546. <https://doi.org/10.1113/jphysiol.1992.sp019243>
 1016 Gabry, J., Simpson, D., Vehtari, A., Betancourt, M., Gelman, A., 2019. Visualization
 1017 in Bayesian workflow. *J. R. Stat. Soc. Ser. A Stat. Soc.* 182, 389–402.
 1018 <https://doi.org/10.1111/rssa.12378>
 1019 Gelman, A., Rubin, D.B., 1992. Inference from iterative simulation using multiple
 1020 sequences. *Stat. Sci.* 7, 457–472. <https://doi.org/10.1214/ss/1177011136>
 1021 Gomez, I.N., Ormiston, K., Greenhouse, I., n.d. Response preparation involves a
 1022 release of intracortical inhibition in task-irrelevant muscles.
 1023 Grandjean, J., Derosiere, G., Vassiliadis, P., Quemener, L., Wilde, Y. de, Duque, J.,
 1024 2018. Towards assessing corticospinal excitability bilaterally: Validation of a
 1025 double-coil TMS method. *J. Neurosci. Methods* 293, 162–168.
 1026 <https://doi.org/10.1016/j.jneumeth.2017.09.016>
 1027 Greenhouse, I., Sias, A., Labruna, L., Ivry, R.B., 2015. Nonspecific Inhibition of the
 1028 Motor System during Response Preparation. *J. Neurosci.* 35, 10675–10684.
 1029 <https://doi.org/10.1523/JNEUROSCI.1436-15.2015>
 1030 Hannah, R., Cavanagh, S.E., Tremblay, S., Simeoni, S., Rothwell, J.C., 2017.
 1031 Selective suppression of local interneuron circuits in human motor cortex
 1032 contributes to movement preparation. *J. Neurosci.* 2869–17.
 1033 <https://doi.org/10.1523/JNEUROSCI.2869-17.2017>
 1034 Hasbroucq, T., Kaneko, H., Akamatsu, M., Possamaï, C.A., 1999. The time-course of

preparatory spinal and cortico-spinal inhibition: an H-reflex and transcranial
 magnetic stimulation study in man. *Exp. brain Res.* 124, 33–41.
 Hasbroucq, Thierry, Kaneko, H., Akamatsu, M., Possamaï, C.A., 1999. The time-
 course of preparatory spinal and cortico-spinal inhibition: An H-reflex and
 transcranial magnetic stimulation study in man. *Exp. Brain Res.* 124, 33–41.
<https://doi.org/10.1007/s002210050597>
 Hasbroucq, T., Kaneko, H., Akamatsu, M., Possamaï, C.A., 1997. Preparatory
 inhibition of cortico-spinal excitability: A transcranial magnetic stimulation study
 in man. *Cogn. Brain Res.* 5, 185–192. [https://doi.org/10.1016/S0926-6410\(96\)00069-9](https://doi.org/10.1016/S0926-6410(96)00069-9)
 Hermans, L., Leunissen, I., Pauwels, L., Cuypers, K., Peeters, R., Puts, N.A.J.,
 Edden, R.A.E., Swinnen, S.P., 2018. Brain GABA levels are associated with
 inhibitory control deficits in older adults. *J. Neurosci.* 0760–18.
<https://doi.org/10.1523/JNEUROSCI.0760-18.2018>
 Hinder, M.R., Puri, R., Kemp, S., Waitzer, S., Reissig, P., Stöckel, T., Fujiyama, H.,
 2018. Distinct modulation of interhemispheric inhibitory mechanisms during
 movement preparation reveals the influence of cognition on action control.
Cortex 99, 13–29. <https://doi.org/10.1016/j.cortex.2017.10.002>
 Hinder, M.R., Schmidt, M.W., Garry, M.I., Carroll, T.J., Summers, J.J., 2011.
 Absence of cross-limb transfer of performance gains following ballistic motor
 practice in older adults. *J. Appl. Physiol.* 110, 166–175.
<https://doi.org/10.1152/japplphysiol.00958.2010>
 Hinder, M.R., Schmidt, M.W., Garry, M.I., Summers, J.J., 2010. Unilateral
 contractions modulate interhemispheric inhibition most strongly and most
 adaptively in the homologous muscle of the contralateral limb. *Exp. brain Res.*
 205, 423–33. <https://doi.org/10.1007/s00221-010-2379-z>
 Hummel, F.C., Steven, B., Hoppe, J., Heise, K., Thomalla, G., Cohen, L.G., Gerloff,
 C., 2009. Deficient intracortical inhibition (SICI): During movement preparation
 after chronic stroke. *Neurology* 72, 1766–1772.
<https://doi.org/10.1212/WNL.0b013e3181a609c5>
 Ibáñez, J., Hannah, R., Rocchi, L., Rothwell, J.C., 2020. Premovement Suppression
 of Corticospinal Excitability may be a Necessary Part of Movement Preparation.
Cereb. Cortex 30, 2910–2923. <https://doi.org/10.1093/cercor/bhz283>
 Irlbacher, K., Brocke, J., Mechow, J. v., Brandt, S.A., 2007. Effects of GABAA and
 GABAB agonists on interhemispheric inhibition in man. *Clin. Neurophysiol.* 118,
 308–316. <https://doi.org/10.1016/j.clinph.2006.09.023>
 Jacqmin-Gadda, H., Fabrigoule, C., Commenges, D., Dartigues, J.F., 1997. A 5-year
 longitudinal study of the Mini-Mental State Examination in normal aging. *Am. J.*
Epidemiol. 145, 498–506.
 Klein, P.-A., Olivier, E., Duque, J., 2012. Influence of Reward on Corticospinal
 Excitability during Movement Preparation. *J. Neurosci.* 32, 18124–18136.
<https://doi.org/10.1523/JNEUROSCI.1701-12.2012>
 Klein, P.A., Duque, J., Labruna, L., Ivry, R.B., 2016. Comparison of the two cerebral
 hemispheres in inhibitory processes operative during movement preparation.
Neuroimage 125, 220–232. <https://doi.org/10.1016/j.neuroimage.2015.10.007>
 Klein, P.A., Petitjean, C., Olivier, E., Duque, J., 2014. Top-down suppression of
 incompatible motor activations during response selection under conflict.
Neuroimage 86, 138–149. <https://doi.org/10.1016/j.neuroimage.2013.08.005>
 Kruschke, J.K., 2018. Rejecting or Accepting Parameter Values in Bayesian
 Estimation. *Adv. Methods Pract. Psychol. Sci.* 1, 270–280.

1085 <https://doi.org/10.1177/2515245918771304>
 1086 Labruna, L., Fern Andez-Del-Olmo, M., Ivry, R.B., 2010. Comparison of different
 1087 baseline conditions in evaluating factors that influence motor cortex excitability.
 1088 Brain Stimul. <https://doi.org/10.1016/j.brs.2010.09.010>
 1089 Lebon, F., Greenhouse, I., Labruna, L., Vanderschelden, B., Papaxanthis, C., Ivry,
 1090 R.B., 2016. Influence of Delay Period Duration on Inhibitory Processes for
 1091 Response Preparation. Cereb. Cortex 26, 2461–2470.
 1092 <https://doi.org/10.1093/cercor/bhv069>
 1093 Levin, O., Fujiyama, H., Boisgontier, M.P., Swinnen, S.P., Summers, J.J., 2014.
 1094 Aging and motor inhibition: A converging perspective provided by brain
 1095 stimulation and imaging approaches. Neurosci. Biobehav. Rev.
 1096 <https://doi.org/10.1016/j.neubiorev.2014.04.001>
 1097 Liuzzi, G., Hörniß, V., Hoppe, J., Heise, K., Zimerman, M., Gerloff, C., Hummel, F.C.,
 1098 2010. Distinct temporospatial interhemispheric interactions in the human primary
 1099 and premotor cortex during movement preparation. Cereb. Cortex 20, 1323–
 1100 1331. <https://doi.org/10.1093/cercor/bhp196>
 1101 Lo, S., Andrews, S., 2015. To transform or not to transform: using generalized linear
 1102 mixed models to analyse reaction time data. Front. Psychol. 6, 1171.
 1103 <https://doi.org/10.3389/fpsyg.2015.01171>
 1104 Lüdecke, D., Waggoner, P., Makowski, D., 2019. insight: A Unified Interface to
 1105 Access Information from Model Objects in R. J. Open Source Softw. 4, 1412.
 1106 <https://doi.org/10.21105/joss.01412>
 1107 Makowski, D., Ben-Shachar, M., Lüdecke, D., 2019a. bayestestR: Describing Effects
 1108 and their Uncertainty, Existence and Significance within the Bayesian
 1109 Framework. J. Open Source Softw. 4, 1541. <https://doi.org/10.21105/joss.01541>
 1110 Makowski, D., Ben-Shachar, M.S., Chen, S.H.A., Lüdecke, D., 2019b. Indices of
 1111 Effect Existence and Significance in the Bayesian Framework. Front. Psychol.
 1112 10. <https://doi.org/10.3389/fpsyg.2019.02767>
 1113 Mars, R.B., Bestmann, S., Rothwell, J.C., Haggard, P., 2007. Effects of motor
 1114 preparation and spatial attention on corticospinal excitability in a delayed-
 1115 response paradigm. Exp. Brain Res. 182, 125–129.
 1116 <https://doi.org/10.1007/s00221-007-1055-4>
 1117 Ni, Z., Gunraj, C., Nelson, A.J., Yeh, I.J., Castillo, G., Hoque, T., Chen, R., 2009.
 1118 Two phases of interhemispheric inhibition between motor related cortical areas
 1119 and the primary motor cortex in human. Cereb. Cortex 19, 1654–1665.
 1120 <https://doi.org/10.1093/cercor/bhn201>
 1121 Nunez, M.D., Vandekerckhove, J., Srinivasan, R., 2017. How attention influences
 1122 perceptual decision making: Single-trial EEG correlates of drift-diffusion model
 1123 parameters. J. Math. Psychol. 76, 117–130.
 1124 <https://doi.org/10.1016/j.jmp.2016.03.003>
 1125 Peirce, J., Gray, J.R., Simpson, S., MacAskill, M., Höchenberger, R., Sogo, H.,
 1126 Kastman, E., Lindeløv, J.K., 2019. PsychoPy2: Experiments in behavior made
 1127 easy. Behav. Res. Methods 51, 195–203. <https://doi.org/10.3758/s13428-018-01193-y>
 1128
 1129 Quoilin, C., Fievez, F., Duque, J., 2019. Preparatory inhibition: Impact of choice in
 1130 reaction time tasks. Neuropsychologia 129, 212–222.
 1131 <https://doi.org/10.1016/j.neuropsychologia.2019.04.016>
 1132 Quoilin, C., Wilhelm, E., Maurage, P., De Timary, P., Duque, J., 2018. Deficient
 1133 inhibition in alcohol-dependence: Let's consider the role of the motor system!
 1134 Neuropsychopharmacology 43, 1851–1858. <https://doi.org/10.1038/s41386-018->

1135 0074-0
 1136 Ratcliff, R., McKoon, G., 2008. The diffusion decision model: Theory and data for
 1137 two-choice decision tasks. *Neural Comput.*
 1138 <https://doi.org/10.1162/neco.2008.12-06-420>
 1139 Sinclair, C., Hammond, G.R., 2009. Excitatory and inhibitory processes in primary
 1140 motor cortex during the foreperiod of a warned reaction time task are unrelated
 1141 to response expectancy. *Exp. Brain Res.* 194, 103–113.
 1142 <https://doi.org/10.1007/s00221-008-1684-2>
 1143 Sinclair, C., Hammond, G.R., 2008. Reduced intracortical inhibition during the
 1144 foreperiod of a warned reaction time task. *Exp. Brain Res.* 186, 385–392.
 1145 <https://doi.org/10.1007/s00221-007-1241-4>
 1146 Singmann, H., Kellen, D., 2019. An Introduction to Mixed Models for Experimental
 1147 Psychology, in: *New Methods in Cognitive Psychology*. pp. 4–31.
 1148 <https://doi.org/10.4324/9780429318405-2>
 1149 Starns, J.J., Ma, Q., 2018. Response biases in simple decision making: Faster
 1150 decision making, faster response execution, or both? *Psychon. Bull. Rev.* 25,
 1151 1535–1541. <https://doi.org/10.3758/s13423-017-1358-9>
 1152 Strauss, S., Lotze, M., Flöel, A., Domin, M., Grothe, M., 2019. Changes in
 1153 Interhemispheric Motor Connectivity Across the Lifespan: A Combined TMS and
 1154 DTI Study. *Front. Aging Neurosci.* 11, 12.
 1155 <https://doi.org/10.3389/fnagi.2019.00012>
 1156 Talelli, P., Waddingham, W., Ewas, A., Rothwell, J.C., Ward, N.S., 2008. The effect
 1157 of age on task-related modulation of interhemispheric balance. *Exp. Brain Res.*
 1158 186, 59–66. <https://doi.org/10.1007/s00221-007-1205-8>
 1159 Tandonnet, C., Garry, M.I., Summers, J.J., 2010. Cortical activation during temporal
 1160 preparation assessed by transcranial magnetic stimulation. *Biol. Psychol.* 85,
 1161 481–486. <https://doi.org/10.1016/j.biopsycho.2010.08.016>
 1162 Theisen, M., Lerche, V., von Krause, M., Voss, A., 2020. Age differences in diffusion
 1163 model parameters: a meta-analysis. *Psychol. Res.* 1–10.
 1164 <https://doi.org/10.1007/s00426-020-01371-8>
 1165 Vandekerckhove, J., Tuerlinckx, F., 2008. Diffusion model analysis with MATLAB: A
 1166 DMAT primer. *Behav. Res. Methods* 40, 61–72.
 1167 <https://doi.org/10.3758/BRM.40.1.61>
 1168 Vassiliadis, P., Grandjean, J., Derosiére, G., de Wilde, Y., Quemener, L., Duque, J.,
 1169 2018. Using a Double-Coil TMS Protocol to Assess Preparatory Inhibition
 1170 Bilaterally. *Front. Neurosci.* 12, 1–14. <https://doi.org/10.3389/fnins.2018.00139>
 1171 von Krause, M., Lerche, V., Schubert, A.L., Voss, A., 2020. Do non-decision times
 1172 mediate the association between age and intelligence across different content
 1173 and process domains? *J. Intell.* 8, 1–28.
 1174 <https://doi.org/10.3390/jintelligence8030033>
 1175 Voss, A., Voss, J., Klauer, K.C., 2010. Separating response-execution bias from
 1176 decision bias: Arguments for an additional parameter in Ratcliff's diffusion
 1177 model. *Br. J. Math. Stat. Psychol.* 63, 539–555.
 1178 <https://doi.org/10.1348/000711009X477581>
 1179 Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L., François, R.,
 1180 Golemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Pedersen, T., Miller,
 1181 E., Bache, S., Müller, K., Ooms, J., Robinson, D., Seidel, D., Spinu, V.,
 1182 Takahashi, K., Vaughan, D., Wilke, C., Woo, K., Yutani, H., 2019. Welcome to
 1183 the Tidyverse. *J. Open Source Softw.* 4, 1686.
 1184 <https://doi.org/10.21105/joss.01686>

1185 Wilhelm, E., Quoilin, C., Petitjean, C., Duque, J., 2016. A Double-Coil TMS Method
1186 to Assess Corticospinal Excitability Changes at a Near-Simultaneous Time in
1187 the Two Hands during Movement Preparation. *Front. Hum. Neurosci.* 10, 1–11.
1188 <https://doi.org/10.3389/fnhum.2016.00088>
1189