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DYNAMICS OF COGNITIVE ACTION CONTROL IN LATE-LIFE DEPRESSION DURING ACTION SELECTION

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List of Abbreviations:

AES: Apathy evaluation scale

C: Congruent Condition

CAC: Cognitive action control

cR2 : conditional R2

CE: Congruency effect

CPT-3: Continuous performance test, third version

CSE: Congruency sequence effect

DRS: Depressive retardation scale

HC: Healthy controls

HDRS: Hamilton depressive rating scale

LLD: Late-life depression

MoCA: Montreal cognitive assessment scale

MCST: Modified Wisconsin card sorting test

mR2 : marginal R2

NC: Non-congruent Condition

ST: Simon Task

STAI: State and Trait Anxiety Inventory

1. INTRODUCTION

Late-Life Depression (LLD), (>60 years old), affects 7% of the population (World Health Organization, 2017). Cognitive control deficits lie at the core of LLD being persistent during remission (Bhalla et al., 2006; Butters et al., 2004; Diniz et al., 2013), correlating with disability and predicting depressive relapses (Alexopoulos et al., 2002, 2000). Cognitive action control (CAC) refers to “a subset of cognitive control processes involved in the requirement to coordinate one’s instantaneous urges vis-à-vis actions that concord with our intentions or instructions” (Ridderinkhof et al., 2011). Such processes include cognitive inhibition, cognitive flexibility or inhibitory control. They can be altered during normal aging (Maldonado et al., 2020; Rey-Mermet and Gade, 2018) but may be magnified in LLD. Indeed, CAC deficits in LLD have been associated with higher suicidality (McGirr et al., 2012; Richard-Devantoy et al., 2015, 2011) possibly mediated by impulsivity (Dombrowski et al., 2011), and apathy (Feil et al., 2003; Funes et al., 2018). However, these studies lack an integrative framework to explore in-depth CAC dysfunction.

The Simon task (ST) is a tool of choice to explore CAC in LLD as it measures electively the integrity of the processes coding for perceptual and action monitoring (Hommel, 2011) and is negligibly influenced by other domains of cognition. During this task, subjects are instructed to make a fast and accurate left or right hand response according to the color of a stimulus that is presented either to the left or right side of a central fixation point (Hedge and Marsh, 1975). Conflict lies in the competition between the location (non-relevant information) and the color of the stimulus (relevant information). During non-congruent trials (i.e. when color and location do not match) participants show longer reaction time (RT) and decreased accuracy compared to congruent trials (i.e. when color and location match). These modifications between non-congruent and congruent conditions, named the congruency effect (CE), are believed to evaluate online CAC. Additionally, RT and error rates are greater when trials congruency alternates (Gratton et al., 1992). This so-called congruency sequence effect (CSE; Duthoo et al., 2014) is an adaptation of CAC to conflict (Botvinick et al., 2001). Hence, the ST provides a unifying paradigm to evaluate online (CE) and adaptive CAC (CSE).

Using the ST, depressive symptoms have been associated with larger CE (Ng et al., 2012) interpreted as a poorer performance. However, the association between depressive symptoms and adaptive CAC has yielded mixed results: decreased CSE in depression during negative feedback (Holmes and Pizzagalli, 2007), no association between symptoms severity and CSE (Ng et al., 2012) and increased CSE in depressed participants (van Steenbergen et al., 2012). This discrepancy might be due to the use of averaged RTs, thereby omitting the temporal dynamics of CAC. To resolve this, we used the activation-suppression model (Ridderinkhof, 2002a). This model incorporates the temporal dynamics of top-down suppression of impulsive action selection by distinguishing a fast and early impulsive action selection from a late and slow selective response suppression. Impulsive action selection results in increased errors for the fastest responses of the participants in conflict situations while selective response suppression of the non-relevant information takes time to buildup and is most evident at the slowest RTs. Discretizing CAC by reaction times is particularly relevant in LLD because it is suggested that abnormal cognitive control is mediated by decreased processing speed (Nebes et al., 2000; Sheline et al., 2006; Snyder, 2013).

1 The main purpose of the present study is to show that patients with LLD have a deficit in both
2 online and adaptive CAC. Secondly, we aim to show that LLD patients have specific patterns
3 of impulsive action selection and selective response suppression. We hypothesized an
4 impulsive behavior in LLD reflected by increased fast errors and lower selective suppression.
5 Finally, we explored how impulsive action selection and selective response suppression of
6 both online and adaptive CAC were associated to apathy and impulsivity.

8 **2. MATERIALS AND METHODS**

10 **2.1. Participants**

11
12 Thirty-one elderly diagnosed with DSM-5 criteria of Major Depressive Disorder and 31
13 healthy elderly controls (HC) participated. LLD group individuals were recruited by their
14 psychiatrist, while HC were recruited from local retirees associations. Inclusion and exclusion
15 criteria were assessed during a psychiatric interview by a trained old-age psychiatrist.
16 Inclusion criteria for the LLD group were: Hamilton Depressive Rating Scale (HDRS,
17 Hamilton, 1960) score > 10. Exclusion criteria were: age < 60 years-old, schizophrenia,
18 bipolar and neurological disorders, history of addiction (tobacco excluded), uncorrected
19 vision or motor impairments, Montreal Cognitive Assessment Scale (MoCA, Nasreddine et
20 al., 2005) score < 20 (Blair et al., 2016; Dautzenberg et al., 2021), cerebral modulation during
21 the last 6 months. Written informed consents were collected. The study was approved by the
22 local ethics committee of Rennes University Hospital in accordance with current French
23 legislation.

25 **2.2. Experimental design**

26
27 We used the Apathy Evaluation Scale (AES, Marin, 1991), the Depressive Retardation Scale
28 (DRS, Widlöcher, 1983), the Urgency Premeditation Perseverance Sensation seeking
29 impulsive behavior scale (UPPS, Whiteside and Lynam, 2001) exploring four dimensions of
30 impulsivity, and the State and Trait Anxiety Inventory (STAI, Spielberger et al., 1983).
31 HDRS quantified depression severity (LLD patients only). General cognitive function was
32 assessed with the MoCA. The Stroop (Golden, 1978), Trail Making Test A and B (Reitan,
33 1958), Modified Wisconsin Card Sorting (MCST, Nelson, 1976) and Continuous
34 Performance tests (CPT-3, Conners et al., 2018) assessed cognitive control, cognitive
35 flexibility, set shifting and sustained plus selective attention, respectively.

37 **2.3. Task and Procedure**

38
39 The ST (**Figure 1**) was programmed under E-prime Professional version 2.0. This task
40 comprised a familiarization phase (72 trials) followed by an experimental one (five blocks of
41 72 trials, with a pause between each block). All stimuli were displayed on a 60 cm white
42 computer screen, placed 90 cm away from the participant. Each trial began with a black
43 fixation cross displayed at the center of the screen for 1000 ms. A blue or yellow circle

1 (target) of 2.1 cm diameter appeared on the right or left side of the cross. The distance
2 between the center of the computer screen and the edge of the circle was of 1.1 cm.
3 Participants were asked to press a blue or yellow button on a computer keyboard with their
4 right or left hand, as quickly and accurately as possible, according to the color of the target
5 while ignoring its position. The position of the target defined the congruency of the trial. The
6 target disappeared as soon as participants pressed one of the two buttons and a new target
7 appeared after a 1550 to 1650 ms randomly defined interval. The position of the color button
8 was pseudo-randomized across participants, and all conditions were pseudo-randomized with
9 an equal number of trials in each condition.

11 **2.4. Behavioral Analysis**

13 Only responses from the experimental phase with RT between 200 and 1500ms and less than
14 three standard deviations from the mean individual RT were analyzed (1.66 % of the trials
15 removed).

16 Main analyses focused on between-group differences in RT and accuracy rates between the
17 congruent (C) and non-congruent (NC) conditions to assess the CE, adding the interaction
18 with preceding congruency for evaluating the CSE. The dynamics of CAC (i.e., impulsive
19 action selection and selective response suppression) were assessed by distributional analyses
20 (Ridderinkhof, 2002b). *Impulsive action selection* is represented by conditional accuracy
21 functions (CAF) which plot correct responses as a function of the *RT distribution of all*
22 *responses* discretized in 5 bins (62 trials per bin per participant) for each condition (C or NC)
23 and each group (HC or LLD). An increased impulsive action selection corresponds to a lower
24 accuracy rate at the first bin of RT (i.e. fastest responses). *Selective response suppression* is
25 represented by delta plots which plot the congruency effect (difference in RT between NC and
26 C conditions) as a function of the *RT distribution of the correct responses*, discretized in 5
27 bins. We then estimated the slopes between these bins (four slopes). According to the
28 activation-suppression model, the steeper the fourth slope is, the more effective the selective
29 suppression on slow responses. We performed the CAF and delta-plots considering
30 systematically the current trial as a function of the congruency of the preceding trial (CSE).

31 Three participants, 2 LLD and 1 HC, were excluded from the distribution analyses because
32 20% of their completed trials were missing.

34 **2.5. Statistical Analysis**

36 Statistical analyses were performed using R software (version 3.0; R core team, 2017). A
37 significance threshold of two-sided $p < 0.05$ was used.

39 **2.5.1. Patients characteristics**

40 Demographic, clinical and psychological data were compared between the LLD and HC
41 groups using χ^2 tests for qualitative variables and independent t-tests (or Wilcoxon's signed-
42 rand test, depending on visual inspection of Q-Q plots).

1 **2.5.2. Behavioral data**

2 As RTs were not normally distributed, they were first converted using a logarithmic
3 transformation.

4 The **CSE on RT** was estimated using a linear mixed model comparing the log RTs between
5 the four conditions and both groups. The fixed factors were the congruency of the preceding
6 trial (Pre_Cong: Pre_congruent vs. Pre_non-congruent), the congruency of the current trial
7 (Congruency: congruent vs. non-congruent) and the group (LLD and HC). Participant was
8 added as a random intercept. Mixed models optimize statistical power as they use all available
9 data, account for intra-subject repeated measures correlation and easily handle unbalanced
10 designs (Hox et al., 2017). As recommended by Nakagawa and Schielzeth (2013), we reported
11 the conditional (cR2) and marginal R2 (mR2) using the {MuMIn} package (Bartoń, 2013).
12 The linear mixed model was executed using the lme function of the {nlme} package (Pinheiro
13 et al., 2013). Post-hoc Tukey-Kramer tests were performed using the {multcomp} package
14 (Hothorn et al., 2008).

15 The **CSE on accuracy** was estimated using a mixed logistic regression model comparing the
16 correct responses between the four conditions and both groups. The fixed factors were the
17 congruency of the preceding trial, the congruency of the current trial and the group.
18 Participant was added as a random intercept. The model was executed with the glmer function
19 of the {lme4} package (Bates et al., 2015). P-values from the logistic models were derived
20 from the Wald Chi-square tests using the {car} package (Fox and Weisberg, 2011).

21 The **CE on RT and accuracy** were estimated from the effect of the congruency of the current
22 trial from the respective models.

23 **Impulsive action selection** was tested using a mixed model logistic regression with accuracy
24 at the first bin of the CAF as the independent variable. 'Group' and 'congruency of the
25 current trial' were fixed factors while 'participant' was added as a random intercept.

26 **Selective suppression** was tested with a linear regression mixed model with steepness of the
27 fourth slope of the delta plots as independent variable and with the same factorial design as
28 for impulsive action selection.

29
30 Statistically different between-group sociodemographic variables were included as covariates.

31 **2.5.3. Behavioral and Clinical Data Relationships**

32 Associations between the ST indices and the clinical scores of LLD were tested using
33 spearman correlations (detailed in supplemental methods).

34
35
36 All codes are available in supplemental material. Clinical and behavioral data are available at
37 the Mendeley data repository (10.17632/5644kyzncp.1).

38 39 **3. RESULTS**

40 41 **3.1. Patient characteristics**

42

1 Between-group sociodemographic, clinical and neuropsychological variables are summarized
2 in **Table 1**. Twenty-seven (87%) LLD patients were taking antidepressants. LLD patients had
3 lower educational status ($p < 0.001$) than HC but comparable age ($p = 0.11$) and sex ratio
4 ($p = 0.57$). Because of the expected effect of education status on cognitive performance
5 (Seblova et al., 2020), all following between-group analyses were adjusted on education
6 status.

8 **3.2. Between group difference on the CE and CSE**

10 **3.2.1. Congruency Effect**

11 RTs were similar between the LLD patients and HC (Group: $\log(\text{RT})$: $F(1, 59) = 3.17$, $p = 0.07$).
12 RTs were longer and accuracy rates lower for non-congruent than for congruent trials across
13 all participants (Congruency: $\log(\text{RT})$, $F(1, 18362) = 2350.39$, $p < 0.0001$, $mR^2 = 0.24$, $cR^2 =$
14 0.33 ; accuracy, $\chi^2(1, 19305) = 246.34$, $p < 0.0001$, $mR^2 = 0.13$, $cR^2 = 0.49$). This CE was
15 significantly different between the groups on accuracy rates (Group \times Congruency: accuracy,
16 $\chi^2(1, 19305) = 15.11$, $p < 0.001$) but not for RT (Group \times Congruency: $\log(\text{RT})$, $F(1, 18362) =$
17 3.45 , $p = 0.06$). Post-hoc analysis showed that LLD patients made more errors on congruent
18 trials (Group: $z = -3.91$, $p < 0.001$) which was not found in non-congruent trials (Group: $z = -$
19 1.24 , $p = 0.57$).

21 **3.2.2. Congruency sequential effect**

22 Across groups, accuracy rates were higher for trials that followed congruent trials in
23 comparison to trials that followed non-congruent trials, as opposed to RTs (Pre_Cong:
24 accuracy, $\chi^2(1, 19296) = 51.58$, $p < 0.0001$; $\log(\text{RT})$, $\chi^2(1, 16888) = 0.014$, $p = 0.91$; **Figure 2**). CE
25 was associated with the congruency of the preceding trial (RT: Congruency \times Pre_Cong:
26 $\log(\text{RT})$, $\chi^2(1, 16888) = 2308.51$, $p < 0.0001$; accuracy, $\chi^2(1, 19296) = 15.11$, $p = 0.0001$). Post-hoc
27 comparisons indicated that the CE was larger when the preceding trial was congruent for both
28 RT (Pre_Cong: $\log(\text{RT})$, $z = -9.06$, $p < 0.001$) and accuracy (Pre_Cong: accuracy, $z = -9.76$, p
29 < 0.001). No group differences were found on the CSE (RT: Group \times Congruency \times
30 Pre_Cong: $\log(\text{RT})$, $\chi^2(1, 16888) = 0.48$, $p = 0.49$; accuracy, $\chi^2(1, 19296) = 0.58$, $p = 0.44$).

32 **3.3. Impulsive action selection**

34 **3.3.1. Between group differences on online impulsive action selection**

35 **Figure 3** shows the dynamics of accuracy as a function of RT for congruent and non-
36 congruent conditions. Across groups, we found a reduced accuracy on the fastest RTs during
37 non-congruent trials (Congruency: $\chi^2(1, 3927) = 273.57$, $p < 0.0001$; $mR^2 = 0.43$, $cR^2 = 0.53$),
38 showing greater impulsive action selection in the non-congruent condition. The RT of the first
39 bins were equivalent between the groups (Group: $\log(\text{RT})$: $F(1, 59) = 0.65$, $p = 0.42$), even
40 when only considering the congruent trials (Group: $\log(\text{RT})$: $F(1, 59) = 0.04$, $p = 0.27$).

41 While no main group differences across congruency was found (Group: accuracy, $\chi^2(1, 59) =$
42 0.99 , $p = 0.32$), there was a significant interaction between group and congruency (Group \times
43 Congruency: accuracy, $\chi^2(1, 3927) = 10.77$, $p = 0.01$). Post-hoc analysis indicates that LLD

1 patients made more errors than HC during congruent trials (Group: $z = -3.44$, $p = 0.003$) and
2 not for non-congruent trials (Group: $z = -0.86$, $p = 0.81$).

3 We found no effect of the group on the reaction times at the first quantile (Pre_Cong x
4 Congruency x Group: $\log(\text{RT})$: $F(1, 59) = 0.46$, $p = 0.50$) particularly when congruent conditions
5 were preceded by non-congruent conditions (Group: $z = 0.036$, $p = 0.73$).

6 7 **3.3.2. Between group differences on adaptation of impulsive action selection**

8 **Figure 4** reports the CAFs of each group as a function of the congruency of the preceding
9 trials. Across groups, the accuracy of the fastest responses was dependent of the congruency
10 of the preceding trial (Pre_Cong: $\chi^2(1, 59) = 116.95$, $p < 0.0001$) as well as the CSE
11 (Pre_Cong x Congruency: $\chi^2(1, 59) = 40.28$, $p < 0.0001$). Hence, an adaptation effect was
12 present on the fastest responses.

13 There was no significant interaction between the group and CSE (Group x Pre_Cong x
14 Congruency: $\chi^2(1, 59) = 2.46$, $p = 0.12$). As the graphical reading of the CAFs suggests
15 between-group differences in impulsive action selection when congruencies in trials change
16 (grey plots in **Figure 4**), we explored an association between ‘Group’ and impulsive action
17 selection for each pair of congruency sequences. Impulsive responses in LLD patients were
18 greater when congruent trials occur after non-congruent trials (Group, $z = -3.13$, $p = 0.03$)
19 compared to HC (**Figure 4D**), not found in other sequences of adaptation (all $p = 0.99$).

20 21 **3.4. Selective response suppression**

22 23 **3.4.1. Between group differences on online selective response suppression**

24 **Figure 5** displays the delta plots for each group. As predicted by the activation–suppression
25 model, the fourth slope was steeper for the slowest RT, without between group differences
26 (Group: slope, $F(1, 56) = 9.55$, $p = 0.008$; $mR^2 = 0.11$, $cR^2 = 0.89$).

27 28 **3.4.2. Between group differences on adaptation of selective response suppression**

29 Delta plots as a function of trial sequence are represented in supplementary materials (**Figure**
30 **S1**). We did not find any significant differences in selective suppression according to the
31 congruency of the preceding trial (Pre_Cong: slope, $\chi^2(1, 56) = 0.08$, $p = 0.78$) and no
32 significant interaction between group and preceding congruency (Group x Pre_Cong: slope,
33 $\chi^2(1, 56) = 0.98$, $p = 0.32$).

34 35 **3.5. Associations between CAC metrics and symptoms severity in LLD**

36
37 We did not find any significant associations between CAC metrics and apathy, impulsivity,
38 depression or anxiety scores in LLD. These results are detailed in supplemental material.

39 40 41 **4. DISCUSSION**

42

1 We combined measures of online CAC (CE) and adaptive CAC (CSE) from the ST to the
2 activation-suppression model (Ridderinkhof, 2002a) to assess impulsive action selection and
3 response suppression. We found mixed results on the integrity of CAC in LLD: while LLD
4 participants showed reduced cognitive control during impulsive action, they had a more
5 effective selective response suppression compared to HC.

7 **4.1. Influence of Depression on Global Cognitive Action Control**

9 Regarding online CAC, we found increased errors in LLD patients on congruent conditions,
10 unlike Ng and colleagues (2012) who found increased error rates in non-congruent trials
11 among sub-depressive adults. However, the task they used required working memory, which
12 may affect CAC by increasing cognitive load (Engström et al., 2017). In contrast, our simpler
13 task was specifically designed to assess the CAC.

14 Regarding overall adaptive control abilities, we found the expected CSE on both accuracy and
15 RTs, suggesting the task was adequately performed. We did not find any group differences,
16 suggesting preserved overall adaptive control abilities in LLD, as shown in adult depression
17 (Dillon et al., 2015; van Steenbergen et al., 2012).

18 The increased errors during congruent trials among LLD participants compared to HC suggest
19 a subtle decreased facilitation of action selection. Indeed, congruent trials facilitate the
20 transformation of a spatial stimulus location into a motor response (Hasbroucq and Guiard,
21 1991; Kornblum and Lee, 1995). Our results suggest this facilitation of the performance by
22 the task-irrelevant dimension of the stimulus is reduced in LLD. In the ST, the CE specifically
23 informs on response selection, as the conflict operates between the response set and the task-
24 irrelevant dimension of the stimulus. This explains why this CE was different from the
25 interference effect at the Stroop test, where the conflict occurs at the stage of stimulus
26 identification (Li et al., 2014).

28 **4.2. Influence of depression on the dynamics of CAC**

30 **4.2.1. Influence of depression on impulsive action selection**

31 CEs associated to LLD are underpinned by an increased impulsive online action selection in
32 congruent condition. All participants had increased errors in non-congruent conditions for the
33 fastest RT in accordance with the activation-suppression hypothesis. LLD participants
34 showed a greater impulsive action selection on congruent trials suggesting a decreased
35 facilitation by the congruent situation, hence a reduced sensitivity to the irrelevant dimension
36 of the stimulus (Dillon et al., 2015).

37 Analysis of impulsive action selection adaptation suggests that the impulsive tendency of
38 LLD may be due to a reduced disengagement of attention from conflict. Similar to HC, LLD
39 improved their responses when a NC trial preceded a NC trial, but showed increased
40 impulsivity when a NC trial preceded a C trial. Thus, LLD subjects were less “helped” by the
41 stimulus location to promote fast and accurate responses after conflict. This is consistent with
42 altered adaptation to ‘aversive’ stimulus like cognitive conflict (Botvinick et al., 2001;
43 Dreisbach and Fischer, 2015) in depression (Disner et al., 2011; Eshel and Roiser, 2010;

1 Meiran et al., 2011). This has been related to impaired attention (Nicoletti and Umiltà, 1994)
2 which LLD participants confirmed by lower CPT scores than HC.

3 4 **4.2.3. Influence of depression on selective response suppression**

5 LLD patients displayed a stronger selective response suppression than HC. This result aligns
6 with studies showing increased electrophysiological markers of inhibition during Go/No-Go
7 task in depression (Ruchow et al., 2008; Zhang et al., 2016). The authors suggested that LLD
8 participants require additional resources to activate inhibition. In our study, mild to moderate
9 depressive subjects may have over-recruited their inhibition resources to improve their
10 performance in the slowest responses. Indeed, HC's last quantile of RT were approximately
11 100ms faster than LLD. A couple of studies found similar results with depressed individuals
12 taking more time to execute a more effective inhibitory control of pre-potent responses than
13 HC (Dillon et al., 2015; Vallesi et al., 2015).

14 The absence of adaptive selective suppression across participants reproduces Ridderinkhof
15 (2002a) as Wylie and colleagues (2010). This result is sound as the suppression of impulsive
16 responses, maximal for the slowest RT, should be less affected by the congruency of the
17 preceding trial.

18 19 **4.3. No association between clinical features and CAC metrics**

20
21 No significant correlation between CAC measures and clinical scores were found in LLD,
22 similarly than previous results (Austin et al., 1999; Quinn et al., 2012). This might be
23 explained by our sample wherein 80% of the patients had mild to moderate depressive
24 symptoms (Zimmerman et al., 2013). As the performance at ST would not have been specific
25 for too severely depressed elderly (Staub et al., 2013), we may have failed to find correlations
26 between clinical severity and CAC measures.

27 LLD patients had higher scores in impulsive urgency and perseverance traits consistent with
28 depressive disorder (d'Acromont and Van der Linden, 2007). The absence of association
29 between impulsivity-trait and CAC has been found previously, reflecting poor consistency
30 between self-reported temperament and cognitive measures in laboratory settings (Cyders and
31 Coskunpinar, 2011; Stahl et al., 2014).

32 Explorative results found no association between anxiety and impulsive action selection nor
33 response suppression. They also suggest a non-linear relationship between anxiety and online
34 CE which might explain the mixed evidence for an association between cognitive inhibition
35 and anxiety (Beaudreau and O'Hara, 2009; Delphin-Combe et al., 2016; König et al., 2021).
36 We observed that anxiety and premeditation as perseverance impulsivities were correlated in
37 LLD, which are in turn associated with shortest CE on RT, consistent with the meta-analysis
38 from Berg and colleagues (2015). However, these analyses have to be interpreted with caution
39 as they are insignificant after p-value correction.

40 41 **4.4. Limitations**

42
43 To better consider our findings, several issues might be raised.

1 The magnitude of the reduced facilitation after conflict found in LLD suggests that it might be
2 a cognitive marker of the LLD. It should be outlined however that while statistically
3 significant, the group difference is marginal and questions the translational potential of this
4 finding. This is likely to be due to the criteria selection in terms of cognitive impairment we
5 used in order to homogenize the population sample.

6 By selecting participants on an estimation of their ability to complete the ST via the MoCA,
7 we may have excluded participants with poor executive functions, thereby reducing the effect
8 size of CAC deficit among LLD. Yet, the ST has shown to be sensitive to modifications in
9 CAC between groups of subjects with preserved executive functioning (Wylie et al., 2010).
10 We cannot rule out the possibility that some members of our sample may have an underlying
11 neurodegenerative condition that is contributing to these low scores. However, a reduced
12 MoCA scores has been found in adult depression without mild cognitive impairment (Blair et
13 al., 2016; Dautzenberg et al., 2021), a score of 20 being the lowest bound of MoCA scores in
14 this population. Hence, we chose a lower threshold of 20 for inclusion and the absence of
15 DSM-5 criteria of mild neurocognitive impairment.

16 Most of LLD patients were under antidepressants and anxiolytic drugs. While being difficult
17 to disentangle effects of drugs from effects of depression, tapering medication was not
18 feasible for ethical reasons.

19 Other parameters of conflict adaptation, as incentives or emotion, were not considered while
20 important (Shenhav et al., 2013) notably in depression (Grahek et al., 2019). Further studies
21 evaluating them may shed light on complementary mechanisms involved in CAC in LLD.

24 **CONCLUSION**

25 Our study suggests that LLD subjects have a modified CAC, originating from increased
26 impulsive errors during congruent trials, which suggest that LLD individuals have marginal
27 difficulties to disengage their attention from conflict. Also, LLD was characterized by an
28 increased selective suppression suggesting an over-recruitment of inhibition resources.
29 Further research should investigate how motivation and emotion might influence these
30 alterations.

33 **AUTHORS' CONTRIBUTIONS**

34 JCR: Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation;
35 Resources; Software; Validation; Visualization; Writing - original draft.

36 JFH: Conceptualization ; Methodology; Software; Validation; Writing - review & editing.

37 JD: Conceptualization ; Methodology; Validation; Writing - review & editing.

38 MG: Conceptualization ; Investigation; Validation; Writing - review & editing.

39 DD: Funding acquisition; Supervision

40 GR: Conceptualization; Funding acquisition; Investigation; Methodology; Project
41 Administration; Supervision; Validation; Writing - review & editing.

42 All authors read and approved the final manuscript.

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CONFLICTS OF INTEREST

None

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TABLES

Table 1
Demographic and Clinical Data for LLD and HC Groups

| | LLD (n = 31) | HC (n=30) | Statistic | p-value |
|--------------------|-------------------------|-------------------------|------------------|----------------|
| Age (years) | 72 ± 14 60 – 88 | 69 ± 10 60 – 83 | t = -1.65 | 0.11 |
| Gender (M:F) | 10:20 | 8:22 | $\chi^2 = 0.32$ | 0.57 |
| Education (years) | 12 ± 5 8 – 16 | 14 ± 3 9 – 21 | t = 3.81 | <0.001 |
| HDRS | 17 ± 9 11 – 32 | NA | | |
| AES | 43 ± 14 23 – 58 | 19.50 ± 2.25 18 – 24 | W = -14.22 | <0.001 |
| DRS | 6 ± 11 0 – 12 | 2 ± 2 0 – 2 | W = -11.68 | <0.001 |
| Anxiety | | | | |
| STAI-A | 57 ± 27 22 – 98 | 27 ± 10.75 20 – 45 | W = -8.36 | <0.001 |
| STAI-B | 52 ± 6 33 – 68 | 35 ± 17.25 22 – 49 | t = -6.69 | <0.001 |
| Impulsivity | | | | |

| | | | | |
|--------------------|-------------------------------|--------------------------------|-----------|-------|
| UPPS-Urgency | 31.00 ± 7.00 17.00 – 38.00 | 24.50 ± 13.25 16.00 – 38.00 | t = -2.64 | 0.011 |
| UPPS-Premeditation | 21.00 ± 7.00 12.00 – 31.00 | 19.00 ± 5.00 12.00 – 28.00 | t = -0.49 | 0.626 |
| UPPS-Perseverance | 19.00 ± 9.00 12.00 – 30.00 | 16.50 ± 5.25 10.00 – 22.00 | W = 308 | 0.010 |
| UPPS-Sensation | 19.00 ± 9.00 12.00 – 41.00 | 23.50 ± 10.75 12.00 – 39.00 | t = 1.40 | 0.168 |

MoCA

| | | | | |
|------------------------|-------------------|-------------------|----------|--------|
| Raw score | 25 ± 4 20 – 30 | 28 ± 2 23 – 30 | W = 4.99 | <0.001 |
| Visuospatial/Executive | 4 ± 2 1 – 5 | 5 ± 1 3 – 5 | | |
| Naming | 3 ± 0 2 – 3 | 3 ± 0 3 – 3 | | |
| Attention | 6 ± 1 3 – 6 | 6 ± 0 4 – 6 | | |
| Language | 2.5 ± 1 2 – 3 | 3 ± 1 2 – 3 | | |
| Abstraction | 1 ± 1 0 – 2 | 2 ± 0 0 – 2 | | |
| Delayed Recall | 3 ± 2 0 – 5 | 5 ± 1 0 – 5 | | |
| Orientation | 6 ± 1 4 – 6 | 6 ± 0 5 – 6 | | |

Stroop test

| | | | | |
|--------------------|---------------------------------|--------------------------------|----------|-------|
| Interference score | -1.31 ± 13.49 -18.10 – 27.00 | 1.20 ± 13.78 -20.53 – 22.87 | t = 1.43 | 0.159 |
|--------------------|---------------------------------|--------------------------------|----------|-------|

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|-----------------------------------|--------------------------------|--------------------------------|-----------|----------|
| Correct responses in Interference | 23.00 ± 22.25 0.00 – 54.00 | 39.00 ± 13.00 19.00 – 67.00 | t = 3.89 | <0.001 |
| TMT - A | 46 ± 15.75 27.00 – 196.00 | 36.50 ± 18 16.00 – 78.00 | W = 543 | P = 0.07 |
| Cognitive flexibility | | | | |
| TMT B-A | 0.73 ± 14.43 -22.87 – 42.00 | 0.00 ± 12.11 -27.00 – 54.00 | W = 284 | 0.503 |
| MCST perseverative errors | 3.00 ± 3.75 0.00 – 9.00 | 1.50 ± 2.00 0.00 – 6.00 | t = -1.89 | 0.064 |
| MCST Complete categories | 6.00 ± 1.75 2.00 – 6.00 | 6.00 ± 0.00 4.00 – 6.00 | W = 402.0 | 0.066 |
| CPT 3 | | | | |
| Detectability | 55.00 ± 19.50 41.00 – 83.00 | 47.00 ± 15.25 30.00 – 69.00 | t = -2.85 | 0.060 |
| HRT | 58.00 ± 9.50 50.00 – 90.00 | 51.00 ± 10.00 39.00 – 68.00 | t = -3.72 | <0.001 |
| HRT SD | 52.00 ± 12.5 33.00 – 85.00 | 47.00 ± 7.00 41.00 – 61.00 | W = 188.5 | 0.018 |
| Simon task | | | | |
| Reaction times (ms) | | | | |
| Mean | 519 ± 190 201 - 1282 | 472 ± 145 237 - 1145 | F=3.17* | 0.07 |
| Congruent | 484 ± 174 201 - 1282 | 439 ± 134 237 - 1145 | | |
| Non-Congruent | 556 ± 184 244 - 1280 | 507 ± 142 363 – 1053 | | |

| Accuracy rates (%) | | | | |
|--------------------|-------------------------------|-------------------------------|-------------------|------|
| Mean | 94.87 ± 3.23 85.62 – 99.37 | 96.05 ± 3.05 83.92 – 99.68 | $\chi^2 = 3.33^*$ | 0.07 |
| Congruent | 97.91 ± 2.19 91.82 – 99.75 | 99.14 ± 0.97 96.79 – 99.75 | | |
| Non-Congruent | 91.83 ± 5.00 79.20 - 98.74 | 92.96 ± 6.2 69.68 - 100 | | |

Summary descriptive results (except for Simon task results):

Median ± Interquartile Range

Min – Max

Acronyms: AES : Apathy Evaluation Scale, χ^2 : Chi-squared test, CPT-3 : Conners Continuous Performance Test third Edition, DRS : Depression Retardation Scale, F: F-test, HC: Healthy Controls, HDRS : Hamilton Depressive Rating Scale, HRT: mean Hit Reaction Times, HRT SD: standard deviation of Hit Reaction Times , LLD: Late-Life Depression participants, MCST: Modified Card Sorting Test; MoCA: Montreal Cognitive Assessment, STAI: State-Trait Anxiety Inventory, t: Student's t-test , TMT B-A: difference in scores between versions B and A of the Trail Making Test, UPPS: UPPS impulsive scale, W: Wilcoxon's signed-rank test.

** Group Effects from mixed-models*

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4 **FIGURES**

5

6 **Figure 1**

7 In the Simon task, subjects are instructed to make a left- or right-hand response as fast and as
8 accurately as possible according to the color of a stimulus that is presented either to the left or
9 right of a fixation cross. **A.** In congruent trials both dimensions of the stimulus (location and
10 color) point to the desired response, facilitating the response of the subject. **B.** In non-
11 congruent trials, the automatic processing of the spatial location of the stimulus (plain arrow)
12 conflicts with the response requested by the controlled processing of color (dotted arrow). The
13 spatial location of the stimulus has to be ignored to produce a correct response, thus leading to
14 increased RT and errors.

15

16 **Figure 2**

17 Mean RT and accuracy rates (% correct) for congruent (C) and non-congruent (NC) trials
18 with respect to the congruency of the preceding trial (preceding trial congruent (PreC) and
19 non-congruent (PreNC)) in each group. Situations in which the congruency of sequential trials
20 changes are shaded in grey. Error bars represent standard error of the mean.

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Figure 3

Conditional accuracy functions for congruent and non-congruent trial LLD and HC. Error bars represent the standard error of the mean.
*: Significant between-group differences.

Figure 4

Conditional Accuracy Functions in individuals with LLD and HC for congruent (C) and non-congruent (NC) trials preceded by congruent trials (PreC) or by non-congruent trials (PreNC). Accuracy rates in the context of shift in congruency are reported in grey-shaded cells. Error bars represent the standard error of the means.
*: Significant between-group differences.

Figure 5

Delta-plot of reaction times of LLD and HC participants. Error bars represent the standard error of the mean.
*: Significant between-group differences between the last slopes.

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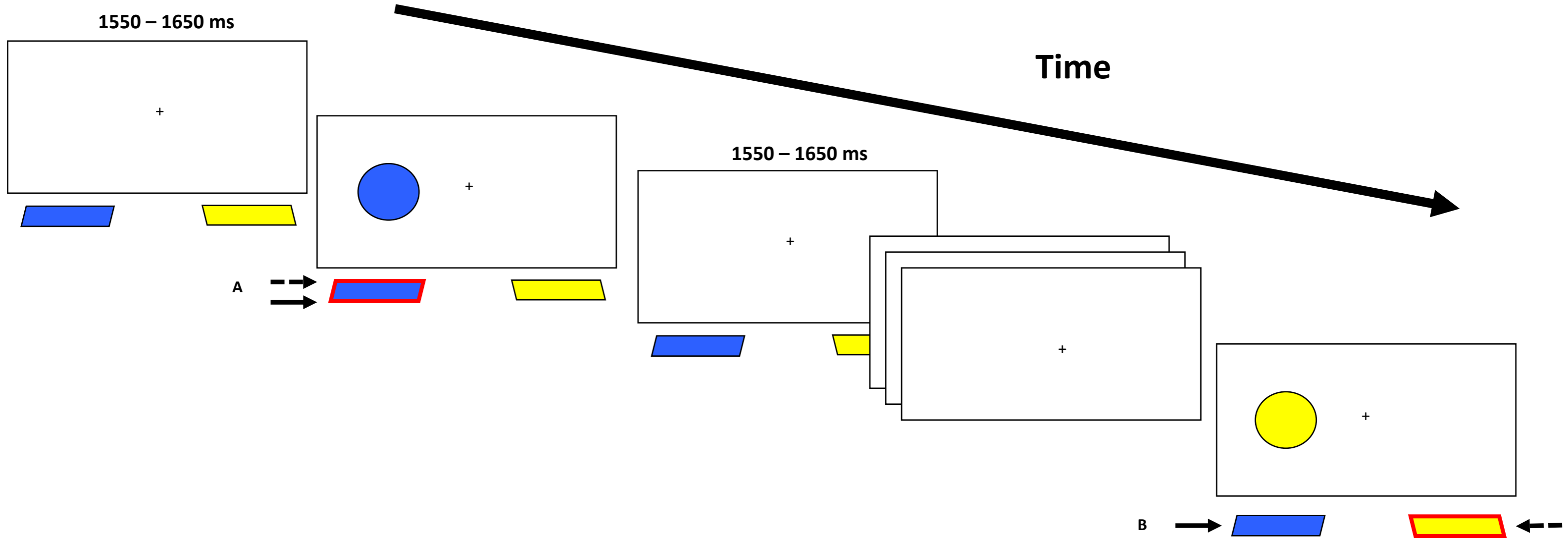
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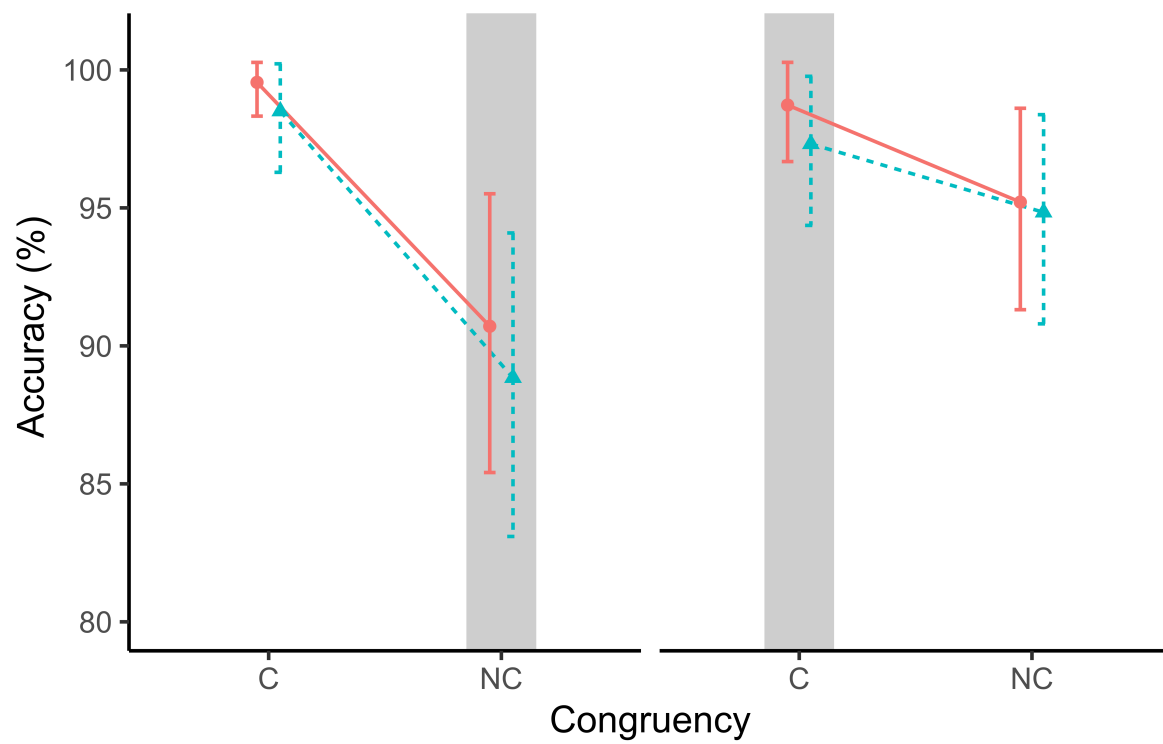
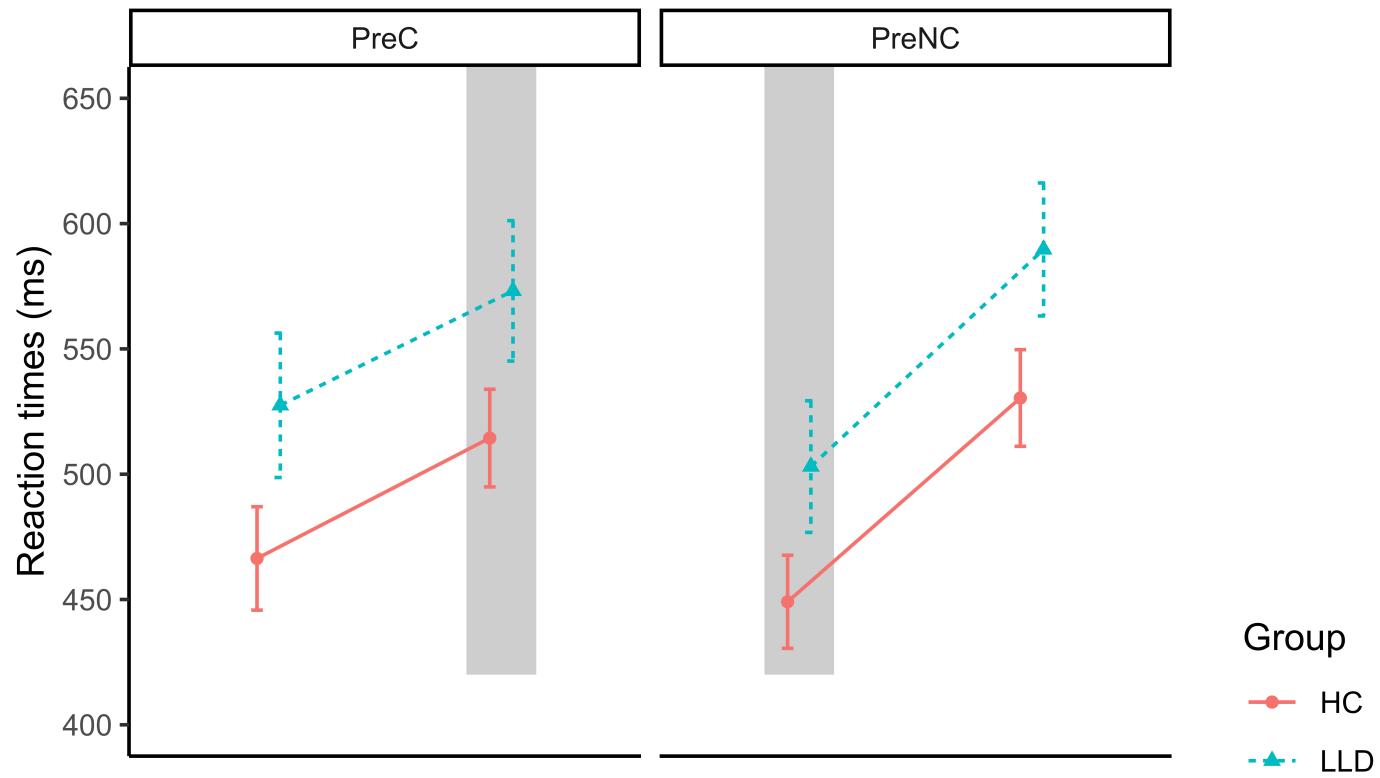
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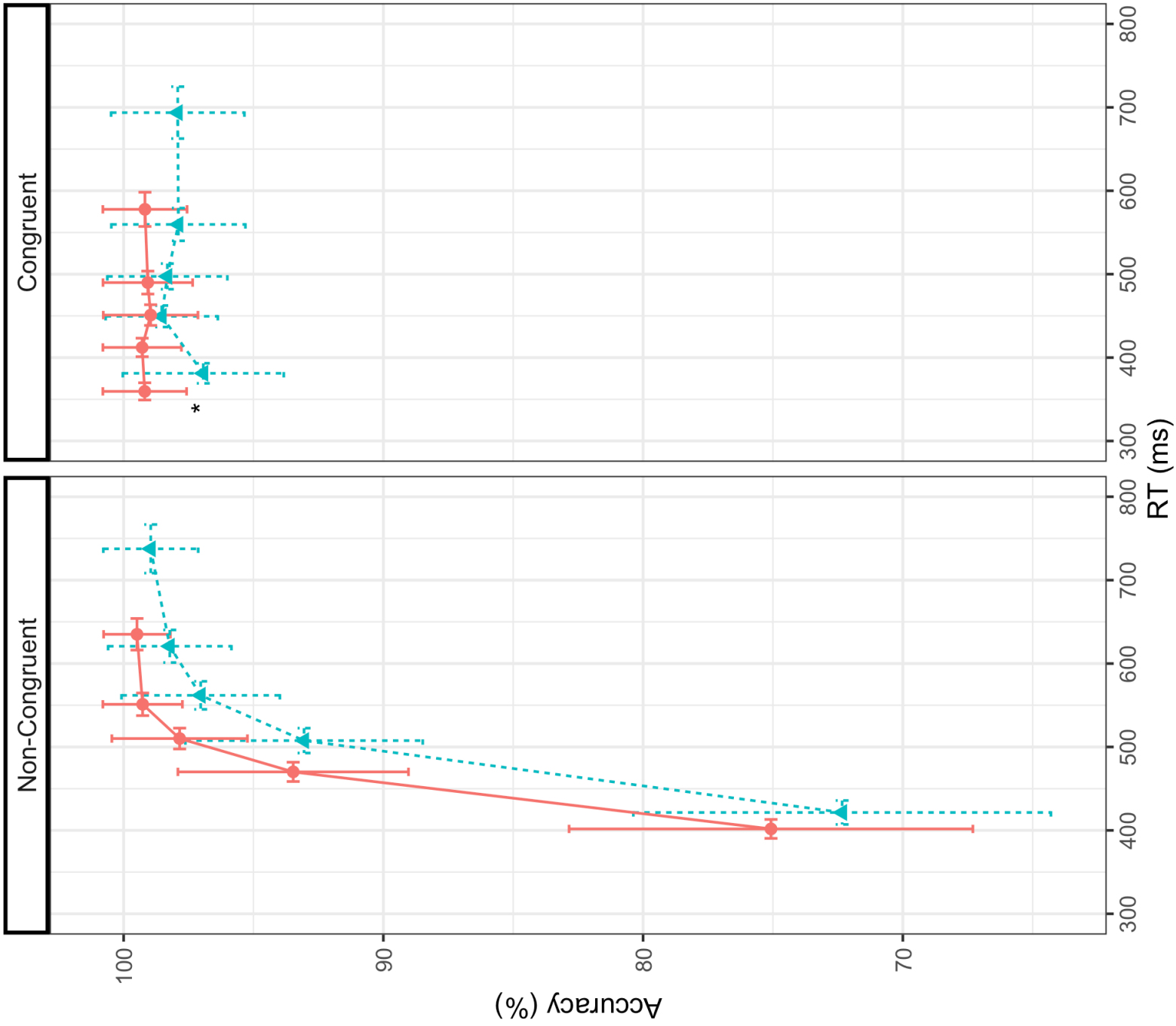
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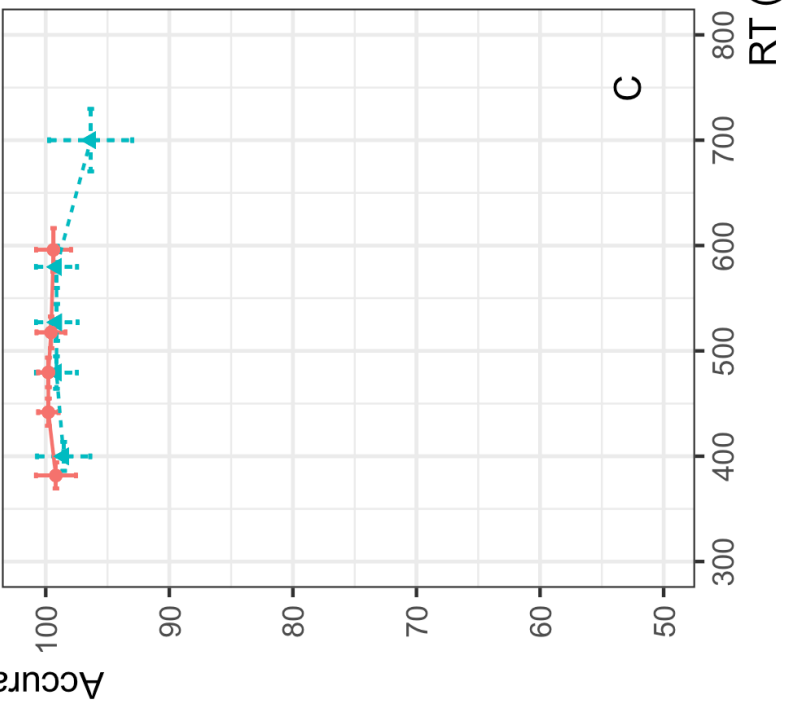
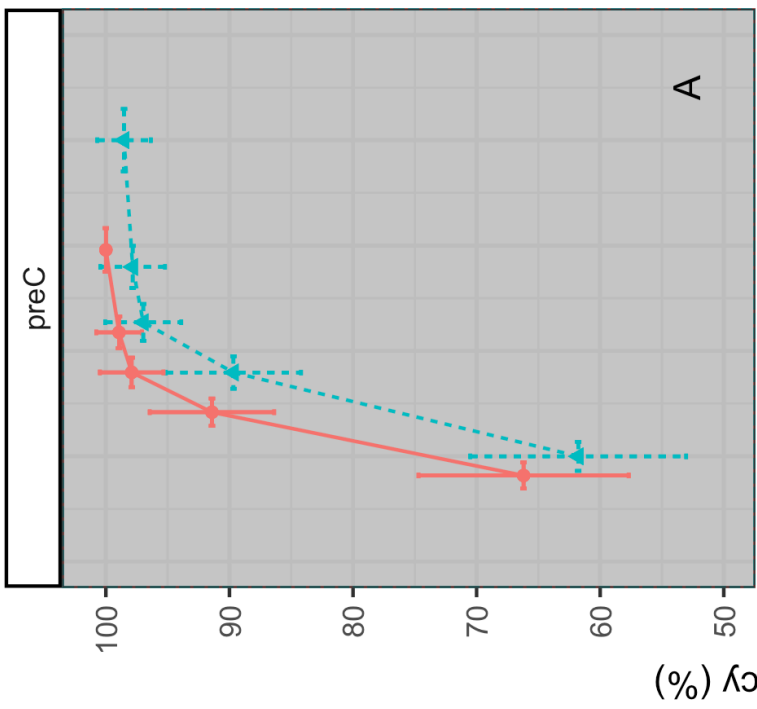
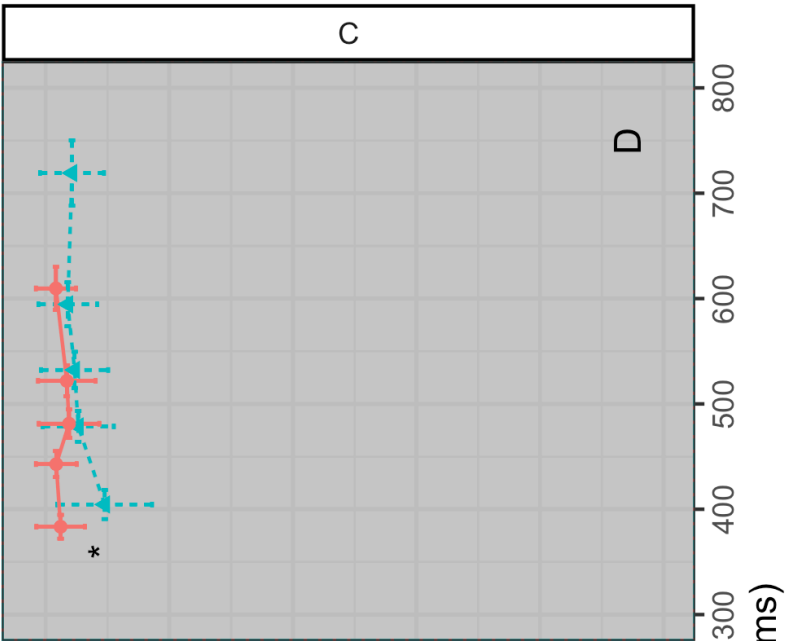
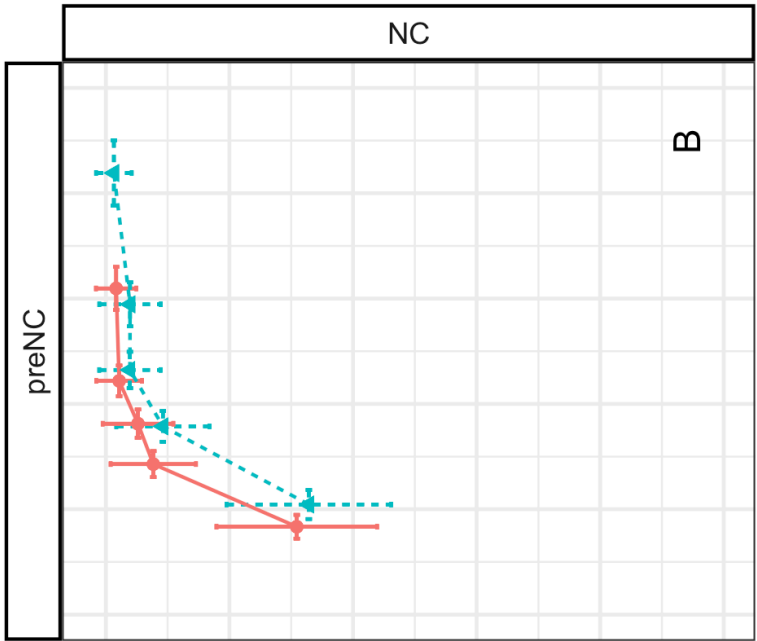
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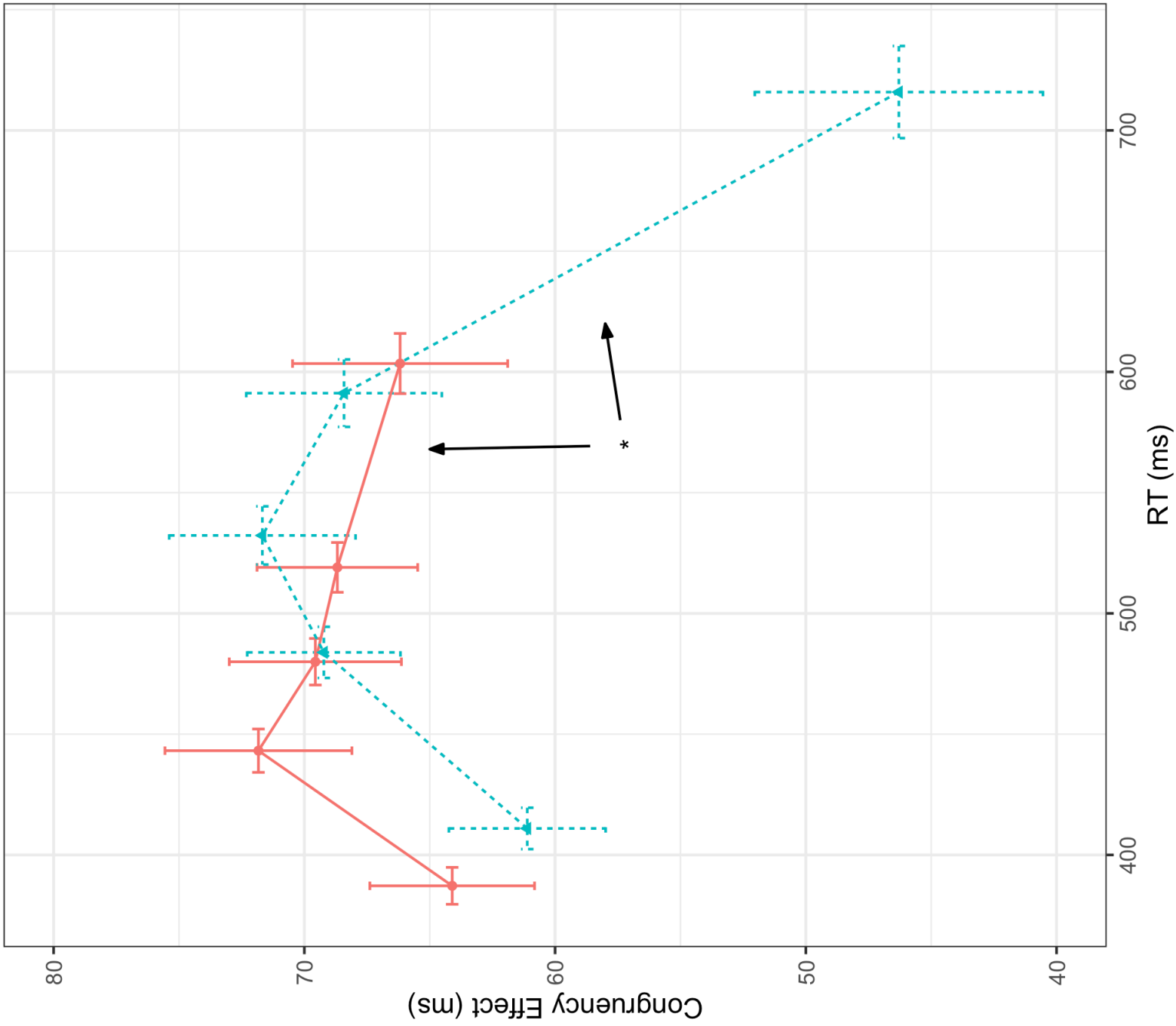




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