Fractionning Reaction Time to probe the validity of the Drift Diffusion Model parameters

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Summary

We designed a two-alternative forced choice experiment in which the by-trial reaction times could be fractionated into pre-motor (PMT) and motor times (MT), based on the onset of muscular activity from the electromyographic (EMG) recordings (Figure 2c). We then compared this empirical decomposition to the decomposition performed by the Drift Diffusion Model (DDM, Ratcliff, 1978). Using these two decompositions, we show that the non-decision time parameter of the DDM is highly correlated with the Motor Time that was recorded when the participants stressed Accuracy over Speed. Furthermore, we show that fitting the by-trial Pre-Motor Time with the DDM mainly modulated the non-decision time parameters. The relative contribution of decision time and motor time components in the overall Reaction Time (based on speed versus accuracy instructions) was observed. Correlation analyses between speed instructions on empirical data suggest that their could be a change in the architecture of cognitive processes rather than a quantitative change between Speed-Accuracy tradeoff (SAT) levels.

The Drift Diffusion Model

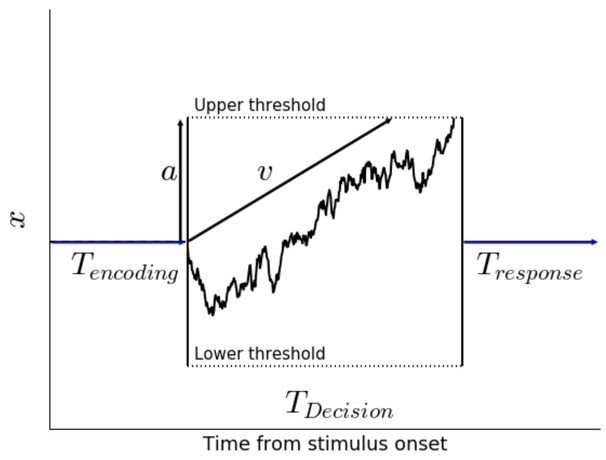

Figure 1: The standard Drift Diffusion Model (Ratcliff, 1978). Parameter a represents the boundary separation parameter, v the Drift Rate, T_{er} the non-decision time thought to contain encoding and response execution processes.

$$RT = T_D + T_{er} \quad (1)$$

$$T_{er} = T_{encoding} + T_{response} \quad (2)$$

$$T_D = \left(\frac{a}{2v}\right)\frac{1 - exp(-va/s^2)}{1 + exp(-va/s^2)} \quad (3)$$

Methods

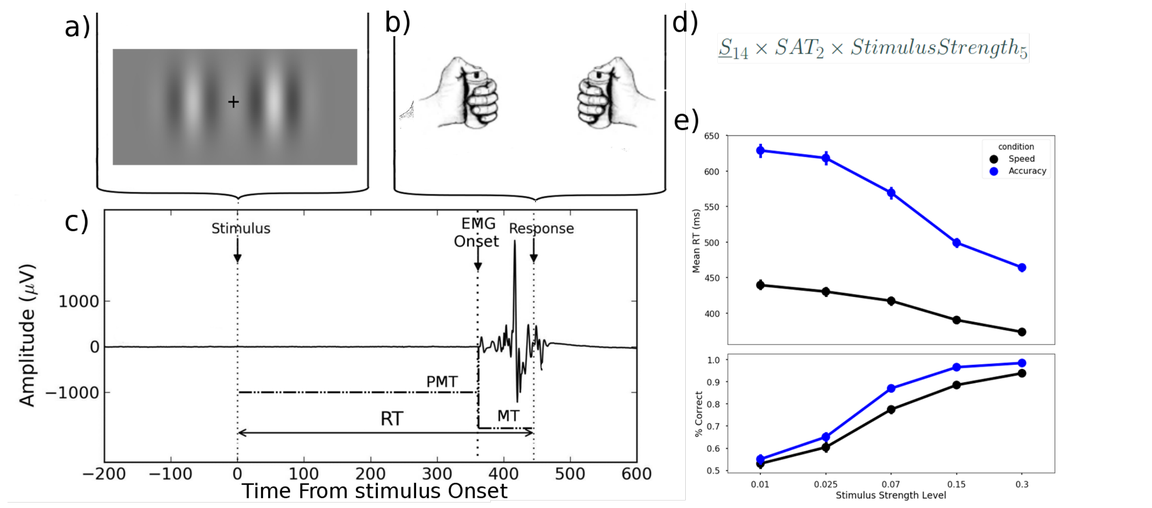

Figure 2: a) Illustration of the stimuli used with the instruction to respond to the most contrasted gabor patch; b) response execution setup; c) Example of the by-trial EMG decomposition, the Pre-Motor Time (PMT) is the time between stimulus and EMG Onset, the Motor Time (MT) the time between the EMG Onset and the mechanical response; d) Experimental design : 14 participants in two Speed/Accuracy conditions (Speed or Accuracy is emphasized), across 5 levels of difficulty; e) Behavioral results of the experiment that show a lower Reaction Time and a lower accuracy when speed is stressed.

Correlation between the DDM parameters and the EMG latencies

Expected relations :

$T_{er} - MT < PMT$

$PMT > T_D$

$MT < T_{er}$

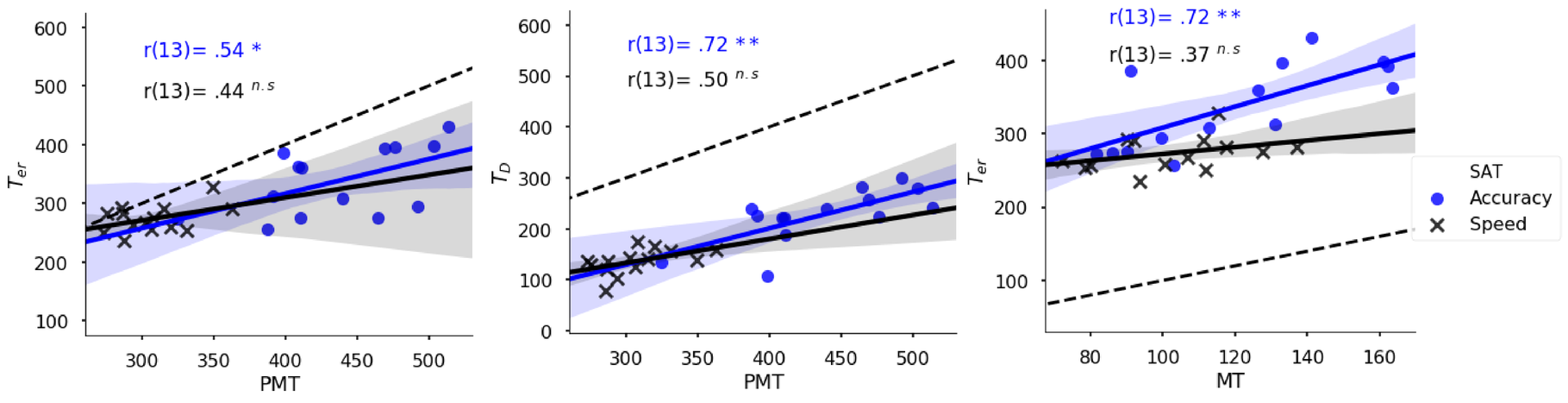

Figure 3: Correlations between the latencies of the empirical decompositions (PMT and MT) and the latencies of the model-based decomposition (T_D and T_{er}) in both SAT emphasis conditions. These figures show that when accuracy is stressed, empirical and model-based decompositions are strongly correlated.

Impact of MT on model fit: comparison of fits on RT and PMT

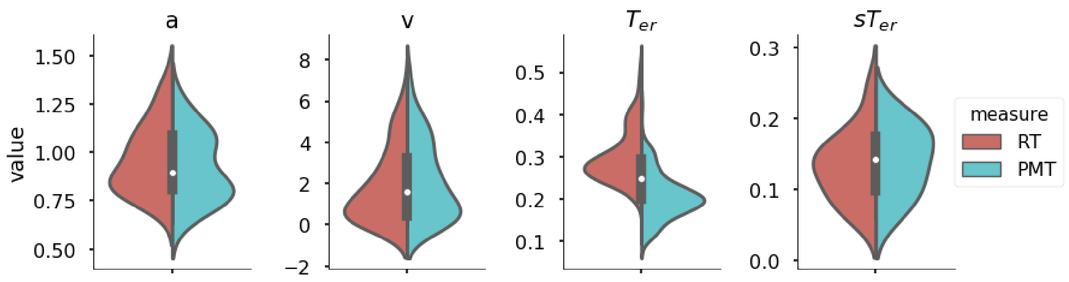

Figure 4: Distribution of parameter values across participants according to Reaction Time fits (red) and Pre-Motor Time fits (blue). This figure shows that removing the MT on a by-trial basis, and fitting the model selectively, impairs selectively the non-decision time.

Distributional properties of the empirical latencies

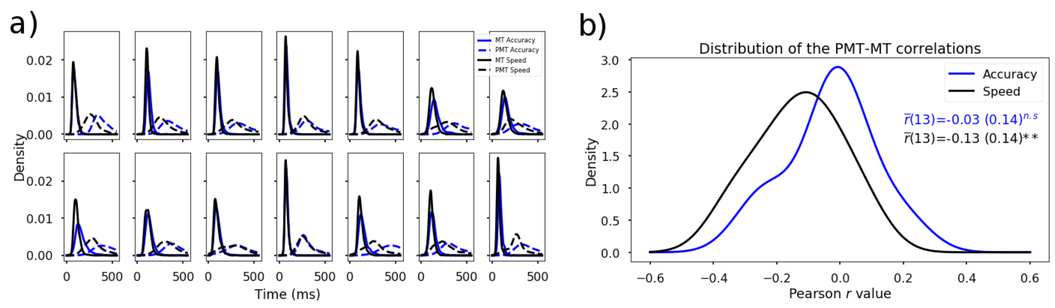

Figure 6: a) Density distributions for both MT and PMT for each participant, in which distributions show high skew for both SAT conditions b) Distributions of the participant correlations between PMT and MT for each SAT condition. When accuracy is stressed, the distribution is centered on zero; and when speed is stressed, the distribution is centered negatively.

Mixed regression on the DDM non-decision time parameter

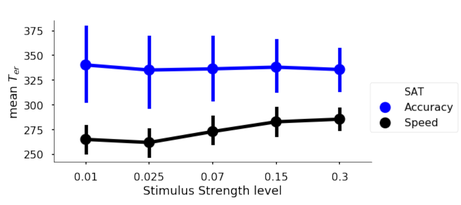

Figure 5: Effect of Speed instructions and stimulus strength level on the estimated non decision time.

Ter :
- SAT: $\beta = -73^{***}$
- Stimulus strength: $\beta = -6^{n.s}$
- SAT*SS Interaction: $\beta = 86^{***}$

Mixed regression on the Motor Time

MT :
- SAT: $\beta = -19^{***}$
- Stimulus strength: $\beta = -28^{***}$
- SAT*SS Interaction: $\beta = 9^{*}$

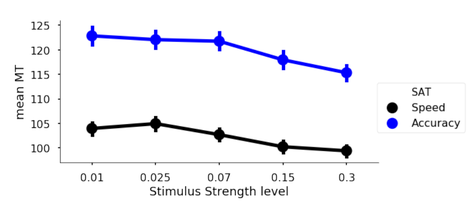

Figure 7: Effect of Speed instructions and stimulus strength level on the recorded Motor Time.

Combining Decompositions

Using the empirical and model-based decompositions, we can assess more specific components of the classic total RT: that is the MT, the Decision Time, and finally the residual non-decision time which is obtained by substracting the measured MT to the theoretical non-decision time : $T_{res} = T_{er} - MT$

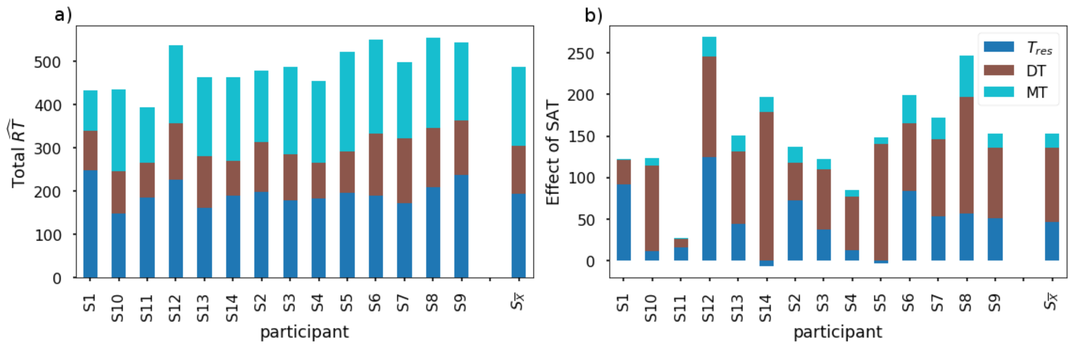

Figure 8: a) Representation of the theoretical composition of the RT, consisting of Decision Time (T_D, 37% of the RT), MT (23%) and residual T_{er} (T_{res} = $T_{er} - MT$, 40%).
b) Representation of each component in the overall SAT effect (Accuracy condition - Speed condition) with a high contribution of T_D (58%), and a weaker contribution of MT (11%) and T_{res} (31%)

Conclusions

- Empirical and model-based decompositions are strongly correlated when accuracy is stressed (figure 3)
- Removing MT (i.e. fitting on PMT) selectively affects the non-decision time parameter (figure 4) suggesting that this theoretical parameter accurately captures the Motor Time we are measuring with EMG.
- The change in the correlation between PMT and MT (figure 6b) suggests that SAT not only affects the individual component of RT, but also modifies their interrelationship.
- Both empirical (figure 7) and model-based decompositions (figure 5) are evidence that non-decisional processes are affected by Speed instructions, which confirms previous results by Spieser et al. (2017).
- Finally, these two decompositions have allowed us to infer that the decision time is just a small part of the total RT (37%), but it however explains most of the Speed instructions effect (58%) (figure 8).
- We note that we have also replicated all of these results in a second experiment with a similar design but with different participants.

References

Ratcliff, R. (1978). A theory of memory retrieval. Psychonomic review, 85(2), 59.
Spieser, L., Servant, M., Hasbroucq, T., & Burle, B. (2017). Beyond decision! Motor contribution to speed–accuracy trade-off in decision-making. Psychonomic bulletin & review, 24(3), 950-956.

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