# Diving Deeper into the Effects of Primed Action on Reaction Time Acceleration

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In this appendix article, we take a closer look at our study results, analyzing the effect of Primed Action on reaction-time improvement. As reported in our paper [10], the Friedman test did not account trial-level variability, which is particularly important for reaction-times, as it is plausible that users' reaction-times could improve over time [1]. Following this rationale, we subsequently explored a follow-up analysis using the Aligned-Rank-Transform (ART) two-way ANOVA [12], which modelled both trials and conditions in a non-parametric manner.

### Results

The ART ANOVA analysis indicated significant effects of the conditions for both the reaction-times (F(2,649)=4.96, p=0.007) and agency-scores (F(2,649)=483.87, p=0) but did not find significant effects of the trials (reaction-times: F(19,649)=1.44, p=0.10; agency-scores: F(19,649)=1.16, p=0.28) or the interactions (reaction-times: F(38,649)=0.89, p=0.67; agency-scores: F(38,649)=1.11, p=0.31).

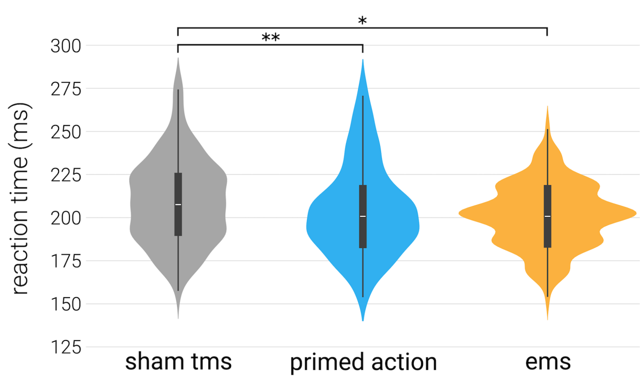


**Figure 1. Reaction-times (*: p<0.05 and **: p<0.01).**

Figure 1 shows the distributions of reaction-times. Pairwise contrast tests via a linear model using Tukey's correction—a standard post-hoc tests for ART ANOVA [2]—showed significant differences between all combinations (*Primed-Action* vs. *sham-TMS*: t-ratio=2.97, p=0.009, Cohen's d =0.27; *EMS* vs. *sham-TMS*: t-ratio=2.40, p=0.043, Cohen's d=0.22), except, as expected, between *Primed-Action* vs. *EMS* (t-ratio=0.57, p=0.84, Cohen's d=0.05).

As can be seen in the violin plots, the deviations are large; thus, we now follow up by examining participants' individual trajectories of reaction-times across conditions.

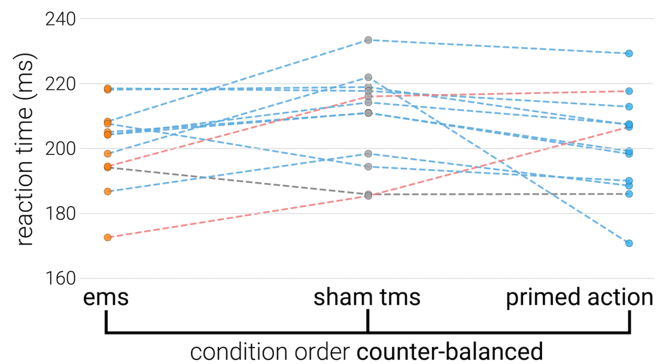


**Figure 2. Individual participants' reaction-times. The condition order was counter-balanced.**

Figure 2 shows individual participants' reaction-times, with lines corresponding to their changes across conditions (note that the order of conditions was counter-balanced). This illustrates that primed action accelerated reaction-time in nine of twelve participants (blue), while others showed slower reaction-times (red) or remained unchanged (gray).

### Discussion

**Smaller effect size for reaction-time.** While the Friedman test (modelling only conditions as a factor) did not find an effect between conditions for the reaction-times, by considering both the effects of conditions and trials (ART ANOVA), we found that *Primed-Action* accelerated reaction-time compared to *sham-TMS* (voluntary action), although the effect size was small (Cohen's d=0.27). Note that this result agrees with prior work in neuroscience, which showed that TMS can shorten the onset of muscle activity [7]. In particular, based on the ART ANOVA analysis, the speedup from *Primed-Action* (M = 201.1 ms) compared to *sham-TMS* (M = 209.0 ms) was found to be ~8 ms.

**Might 8 ms matter in any reaction-time tasks?** We believe that 8 ms might impact certain types of interactive experiences. In competitive video gaming (eSports), the standard input refresh rate is over 240Hz (i.e., ~4 ms per frame) [5]. Thus, a user with an 8 ms faster reaction-time can input their action two frames ahead of opponents [6]. Moreover, 8 ms is significant in other fast-paced activities, e.g., ping-pong, where the ball travels 16-22 cm in 8 ms [8]; the interval can be the difference between missing/hitting.

To allow other researchers to run their analysis using any alternative methods they see fit, we made our data public[1].

[1] Dataset at https://lab.plopes.org/#primed-action.

## REFERENCES


[1] Ando, S., Kida, N. and Oda, S. 2002. Practice Effects on Reaction Time for Peripheral and Central Visual Fields. *Perceptual and Motor Skills*. 95, 3 (Dec. 2002), 747–751. DOI:https://doi.org/10.2466/pms.2002.95.3.747.

[2] Elkin, L.A., Kay, M., Higgins, J.J. and Wobbrock, J.O. 2021. An Aligned Rank Transform Procedure for Multifactor Contrast Tests. *The 34th Annual ACM Symposium on User Interface Software and Technology* (New York, NY, USA, 12 2021), 754–768.

[3] Houzé, B., Bradley, C., Magnin, M. and Garcia-Larrea, L. 2013. Changes in Sensory Hand Representation and Pain Thresholds Induced by Motor Cortex Stimulation in Humans. *Cerebral Cortex*. 23, 11 (Nov. 2013), 2667–2676. DOI:https://doi.org/10.1093/cercor/bhs255.

[4] Kasahara, S., Nishida, J. and Lopes, P. 2019. Preemptive Action: Accelerating Human Reaction using Electrical Muscle Stimulation Without Compromising Agency. *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (New York, NY, USA, Summer 2019), 1–15.

[5] Monitor Refresh Rates - Why More Is Better For Gaming: 2022. *https://prosettings.net/blog/60hz-vs-144hz-vs-240hz/*. Accessed: 2024-09-09.

[6] Murakami, K. and Miyachi, H. 2022. A Study on the Impact of High Refresh-Rate Displays on Scores of eSports. *Advances in Networked-Based Information Systems* (Cham, 2022), 283–288.

[7] Pascual-Leone, A., Valls-Solé, J., Wassermann, E.M., Brasil-Neto, J., Cohen, L.G. and Hallett, M. 1992. Effects of focal transcranial magnetic stimulation on simple reaction time to acoustic, visual and somatosensory stimuli. *Brain*. 115, 4 (Aug. 1992), 1045–1059. DOI:https://doi.org/10.1093/brain/115.4.1045.

[8] Speed of a Table Tennis Ball & Comparison with other sports: 2020. *https://ttcrunch.com/articles/speed-of-table-tennis-ball/*. Accessed: 2024-09-09.

[9] Tajima, D., Nishida, J., Lopes, P. and Kasahara, S. 2022. Whose Touch is This?: Understanding the Agency Trade-Off Between User-Driven Touch vs. Computer-Driven Touch. *ACM Trans. Comput.-Hum. Interact.* 29, 3 (14 2022), 24:1-24:27. DOI:https://doi.org/10.1145/3489608.

[10] Tanaka, Y., Mathews, H. and Lopes, P. 2025. Primed Action: Preserving Agency while Accelerating Reaction-time via Subthreshold Brain Stimulation. *Proceedings of the 38th Annual ACM Symposium on User Interface Software and Technology* (New York, NY, USA, 2025).

[11] Wegner, D.M. 2003. The mind’s best trick: how we experience conscious will. *Trends in Cognitive Sciences*. 7, 2 (Feb. 2003), 65–69. DOI:https://doi.org/10.1016/S1364-6613(03)00002-0.

[12] Wobbrock, J.O., Findlater, L., Gergle, D. and Higgins, J.J. 2011. The aligned rank transform for nonparametric factorial analyses using only anova procedures. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 7 2011), 143–146.