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Saccadic “adaptation” at late target reappearance

Anne Hillairet de Boisferon, Céline Paeye

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Introduction

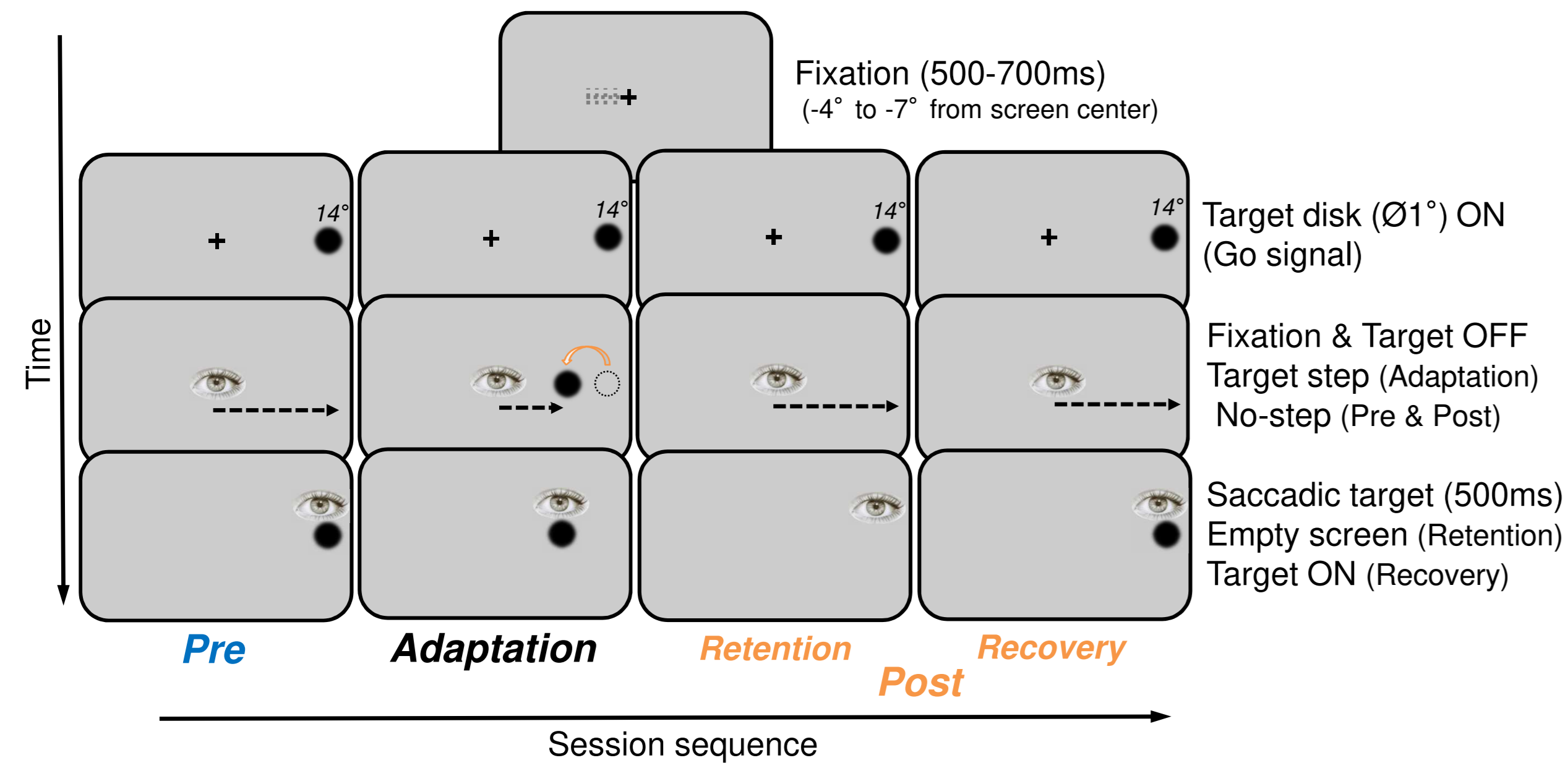
Oculomotor plasticity allows constant adjustments of saccade amplitudes to a changing environment. Saccadic adaptation in humans is however disrupted when the presentation of the post-saccadic target is delayed (100-400ms), and disappears at delays around 600ms. This generally accepted result is however based on two small research samples (6 subjects in total)[1,2]. In this study, we examined the effect of various temporal delays of target displacements on the amount of adaptation to establish the critical time window for what can be considered as sensorimotor saccadic adaptation. Because target displacements are likely perceived in long delay conditions, participants' modification of saccadic amplitude should involve more explicit (voluntary and fast) learning in addition to implicit learning (automatic and slow). In this study, we then evaluated both components of motor adaptation at each delay.

Methods

Backward Adaptation

Three phases during a same session:

- Pre-adaptation (100 trials) / Adaptation (4x100 trials) / Post-adaptation: Retention (no feedback) or Recovery (washout) (100 trials)



Five time delays for target reappearance:

- 20, +60, +300, +600 and +1200ms by reference to saccade landing

Progressive modification of target step size during Adaptation:

- Trials 101-200 = 11%
 - Trials 201-300 = 22%
 - Trials 301-500 = 33%
- of target initial eccentricity (14°)

Participants

188 adults (28 males, 160 females), $M_{age} = 21 \pm 6$ year-olds

- Delay: -20, $n = 39$; +60, $n = 37$; +300, $n = 38$; +600, $n = 38$; +1200, $n = 36$
- Post-Adaptation: recovery, $n = 62$; retention, $n = 68$ (divided in ~12-15 participants per delay)

Data analyses

Percent Change in saccade amplitude

$$PC = \frac{Amplitude_{Ada \text{ or } Post} - Amplitude_{Pre}}{Amplitude_{Pre}} \times 100$$

Mean amplitudes are based on the last 40 valid trials of each phase

Saccade amplitude variability (U-value)

$$U = \frac{-\sum(\rho b \log_2(\rho b))}{\log_2(B)}$$

ρ represents the relative frequency of a bin b and B the number of bins ($B=11$). U-value reflects the likelihood of a saccade amplitude falling in each bin. $U = 0$, there is no uncertainty; $U = 1$, indicates the maximum entropy

Δ Slow-Fast State of the adaptative process

$$\Delta = \frac{Slow \ State - Fast \ State}{Slow \ State + Fast \ State}$$

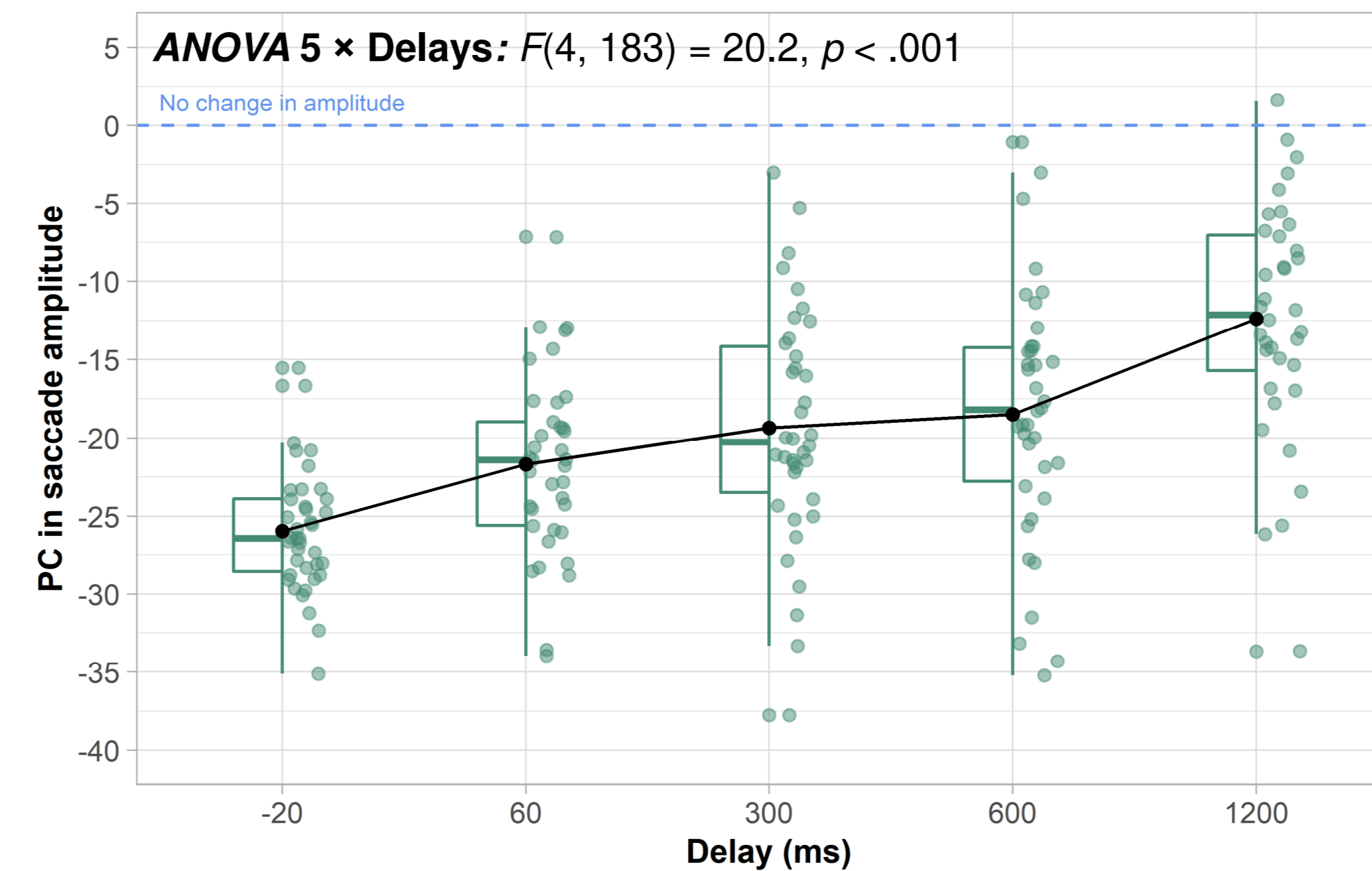
For computational details regarding estimated fast and slow states of the adaptive process during sensorimotor adaptation, see Albert & Shadmehr (2018) [3]

Anne Hillairet de Boisferon & Céline Paeye

Université Paris Cité, Laboratoire Vision Action Cognition, F-92100 Boulogne-Billancourt, France

Results

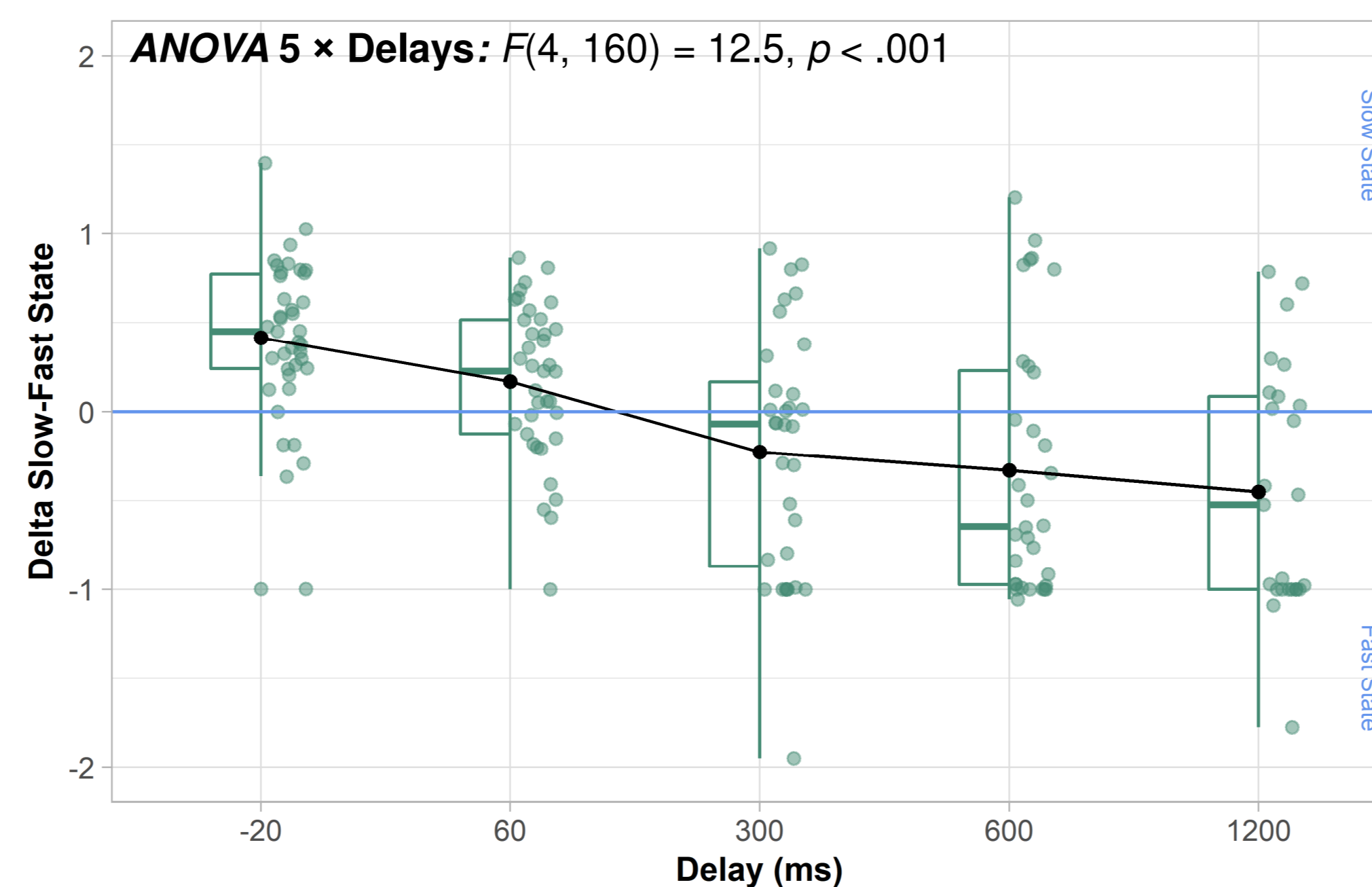
Percent Change in saccade amplitude



At the end of the Adaptation phase, PC in saccade amplitude is less important for the +1200ms delay. (Tukey HSD, all $p_s < .05$)

One-sample t-test – PC_{Ada} vs. 0% change for each delay; all $p_s < .001$

Δ Slow-Fast State for 'adapters'



One-sample t-test – Δ vs. 0 for each delay; $p_s < .05$, except for +300ms ($p = .076$) During sensorimotor adaptation, slow state dominates the adaptive process in the 20, and 60ms delays, whereas fast state dominates during the +600 and +1200ms delays. For the +300ms delay, both processes are equally at play.

Post-adaptation in Retention

Percent Change ~ Delay + Phase + Delay:Phase + (1|Participant)

Delay: $F(4,63) = 6.58, p < .001$; Phase: $F(1,63) = 85.9, p < .001$; Delay*Phase: $F(4,63) = 3.37, p = .02$ (Satterthwaite's method)

The amount of adaptation reduced between the adaptation phase and the post-adaptation phase for each delay (simple effects, $p_s < .001$), except for the +1200ms delay ($p = .16$).

One-sample t-test – PC_{Post} vs. 0% change for each delay, all $p_s < .005$.

Conclusion

Preliminary results show that saccades' amplitude is modified up to a 1200ms delay in the appearance of the post-saccadic target, and that this amplitude reduction is still visible in large proportion after a 600ms delay. Our visual system continues to 'adapt' eye movements even when target displacements are outside the SSD time window, and perceived. We however observed that latencies and variability in saccadic amplitude increased starting from a 300ms delay. We suggest that it could reflect participants' attribution of target displacements to a change in the environment (and not to saccadic errors), and their tendency to 'search for the target'. We indeed observed for the 300 and 600ms delays, that explicit components of motor learning gradually prevailed over implicit ones during the adaptive process, without entirely suppressing them. Finally, after the perturbation was removed, we observed a complete washout of adaptation from a 300ms delay in the recovery condition, but an incomplete return to the baseline in the retention condition for all delays. Overall, this suggests some implicit learning even at late target reappearance. More research is nonetheless needed to determine the exact nature of the mechanisms at play in oculomotor learning.

References

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- [2] Bahcall, D. O., & Kowler, E. (2000). The control of saccadic adaptation: implications for the scanning of natural visual scenes. *Vision Research*, 40(20), 2779-2796.
- [3] Albert, S. T., & Shadmehr, R. (2018). Estimating properties of the fast and slow adaptive processes during sensorimotor adaptation. *Journal of Neurophysiology*, 119(4), 1367-1393.

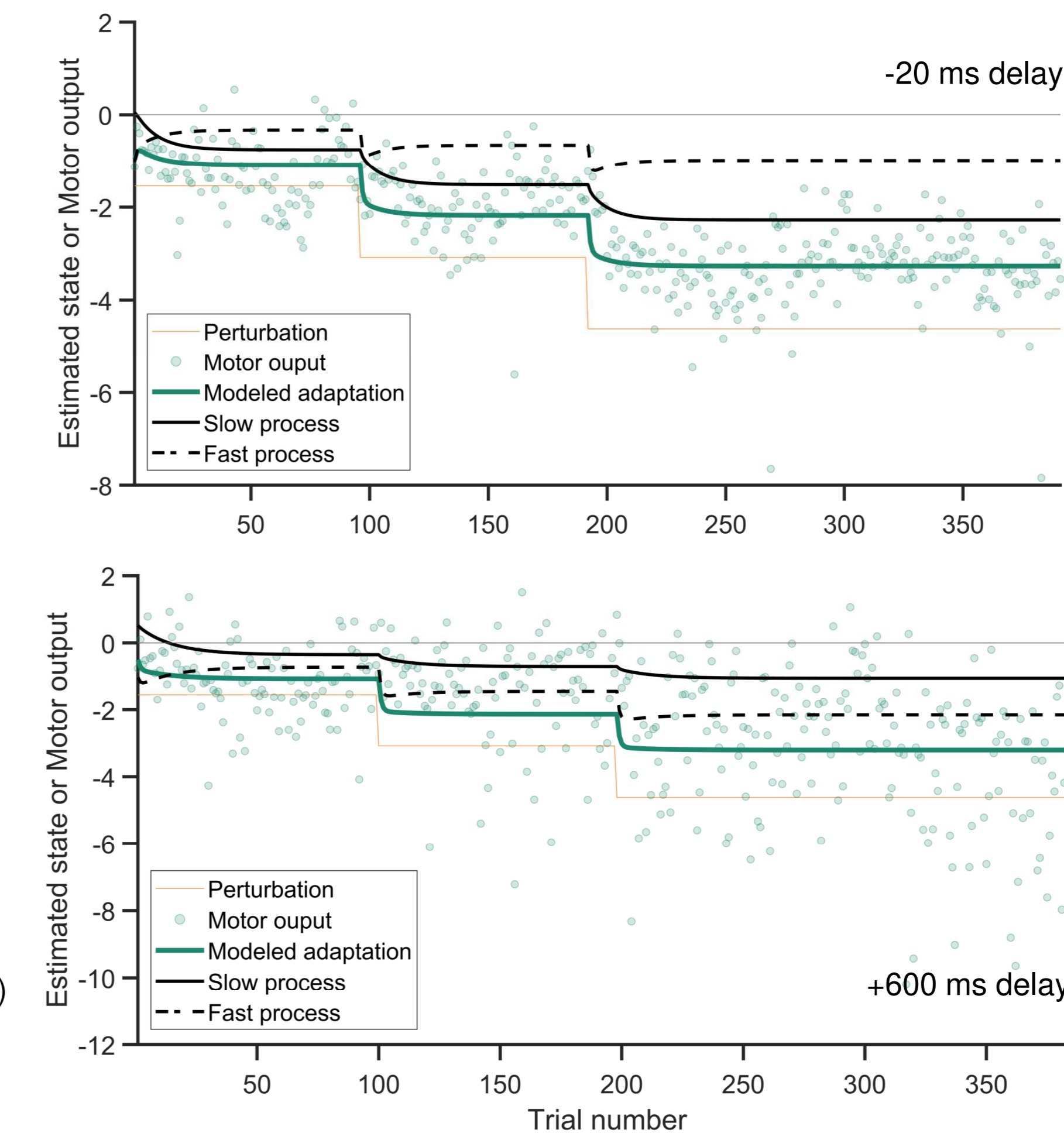
Delay	Adaptation					Post-Adaptation			
	Latency (ms)	U-Value	PC Amplitude	Δ Slow-Fast State*	Adapter**	Retention PC Amplitude	One-sample t-test vs. 0% change	Recovery PC Amplitude	One-sample t-test vs. 0% change
-20	185 ± 32	0.52 ± .07	-26 ± 3.9	0.42 ± .44	39/39	-20.7 ± 3.8	$p < .001$	-16.3 ± 3.9	$p < .001$
+60	189 ± 37	0.54 ± .06	-21.7 ± 5.8	0.17 ± .44	37/37	-17.7 ± 5.3	$p < .001$	-7.6 ± 4.4	$p < .001$
+300	201 ± 51	0.60 ± .07	-19.3 ± 7.6	-0.23 ± .70	32/38	-14 ± 6.5	$p < .001$	-3.2 ± 5.7	$p = .081$
+600	208 ± 27	0.59 ± .07	-18.5 ± 8.1	-0.33 ± .72	32/38	-12.1 ± 6.6	$p < .001$	-2.2 ± 3.8	$p = .075$
+1200	206 ± 39	0.57 ± 0.8	-12.4 ± 7.6	-0.45 ± .69	25/36	-10.1 ± 9.8	$p = .004$	-1.1 ± 3.3	$p = .25$

* Δ_s Slow-Fast State are only computed for adapters.

** Adapter = individual PC_{Ada} in saccade amplitude significantly differs from Pre-adaptation natural variability in saccade amplitude.

Estimation of the Fast and Slow States of the adaptive process during the adaptation phase

(for two representative participants)



U-Value – Adaptation phase

U-Value ~ Delay + Phase + Delay:Phase + (1|Participant)

Delay: $F(4,184) = 2.40, p = .051$; Phase: $F(1,184) = 247, p < .001$; Delay*Phase: $F(4,184) = 9.13, p < .001$ (Satterthwaite's method)

Intra-individual variability is more important in the adaptation phase in comparison to the pre-adaptation phase for each delay (simple effects, all $p_s < .005$).

Variability is less important for the -20ms delay in comparison to the +300, +600 and +1200ms delays in the adaptation phase (Tukey HSD, $p_s < .05$).

Saccade latency – Adaptation phase

Log Latency ~ Delay + Phase + Delay:Phase + (1|Participant)

Delay: $F(4,184) = 0.72, p = .58$; Phase: $F(1,184) = 71.7, p < .001$; Delay*Phase: $F(4,184) = 5.85, p < .001$ (Satterthwaite's method)

Latencies are more important for the +300, +600 and +1200ms delays in the adaptation phase in comparison to the pre-adaptation phase (simple effects, $p_s < .001$).

Post-adaptation in Recovery

Percent Change ~ Delay + Phase + Delay:Phase + (1|Participant)

Delay: $F(4,57) = 14.6, p < .001$; Phase: $F(1,57) = 232.2, p < .001$; Delay*Phase: $F(4,57) = 1.49, p = .22$ (Satterthwaite's method)

The amount of adaptation reduced between the adaptation phase and the post-adaptation phase for each delay (simple effects, all $p_s < .001$)

One-sample t-test – PC_{Post} vs. 0% change for each delay. $p_s < .001$, for the -20 and +60ms delays.