Biphasic ERP responses are not just filter artifacts

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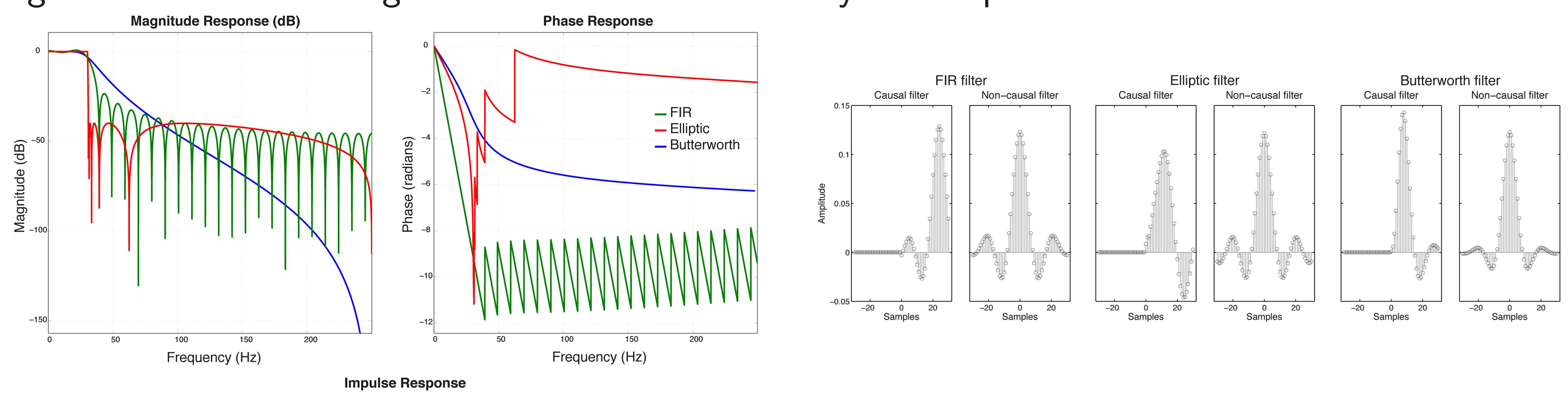
Introduction

Filtering is one of the most basic yet most poorly understood steps in a typical ERP analysis. Filters fundamentally change the data in ways beyond just the desirable, a fundamental fact which has seen increasing attention and debate in the literature.[1–5] Recently, Tanner et al. have demonstrated that high-pass filtering can introduce spurious components before a real effect, e.g. an N400 before a P600.[6] This raises the question whether the different component patterns observed across languages for the same manipulation are an artifact of different filtering practices.

Describing and classifying filter response

Filter distortions are related to two fundamental properties of filtering: filters remove parts of the signal and there is no digital filter which removes only the frequencies that we want.



Magnitude response a frequency-domain description of how a filter interacts with input signals.

Phase response the difference in phase, at a particular frequency, between an input sine wave and the output sine wave at that frequency.

Impulse response a digital filter's time-domain output sequence when the input is a single unity-valued sample (**impulse**) preceded and followed by zero-valued samples.

images reproduced from [3], definitions adapted from [7]

Phase response: time-shifting in filtering

Filtering impacts both the amplitude and temporal relationships of constituent frequencies.

Group delay can be thought of as the propagation time delay of the information of an amplitude-modulated signal (e.g. ERP) passing through a digital filter. Non-constant passband group delay leads to distortion because different frequencies take different amounts of time to pass through the filter.

Causal filters are computed only from past input and necessarily introduce group delay, thus distorting component latencies.

Non-causal filters are computed (offline) from both past and future input and can achieve zero-phase (and thus zero group delay) at the cost of smearing filter artifacts forward and backward in time.

adapted in part from [7], cf. [3, 4, 8]

Infinite vs. finite impulse response in filtering

Characteristic	IIR	FIR (non-recursive)
Number of necessary multiplications	Least	Most
Stability	Must be designed	Guaranteed
Can simulate prototype analog filters	Yes	No
Required coefficient memory	Least	Most

adapted from [7]

Although offering potential computational advantages, the potentially *infinitely long* artifacts as well as the necessity of forward-backward filtering to achieve zero-phase are disadvantages of IIR filters.

Data

Data were reanalysed from [9]. For simplicity of presentation and analysis, we restricted ourselves to the *motion* contrast and the posterior electrodes, where both N400 and the P600 are canonically strongest. The originally reported effect was a biphasic N400-P600 response for the violation condition.

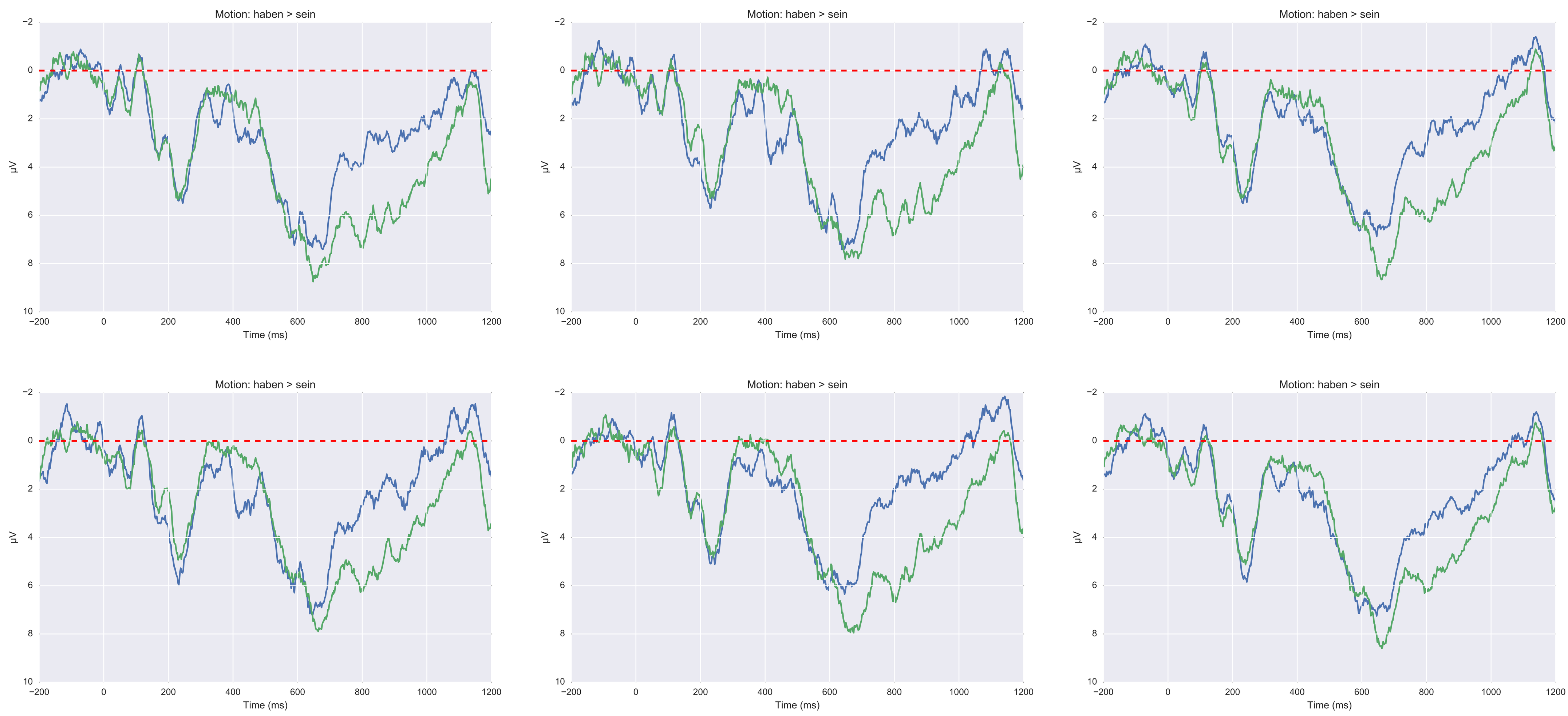
Beyond the passband: impulse-response type makes a difference

Causal filters have been proposed as a solution to the types of distortions observed by [6] at the cost of distorting (absolute) component latencies.[3, 4, 8] While this seems a viable option for less peaky endogenous components such as the N400, many popular analysis packages do not offer a causal filter option. Here, we focused on the effect of impulse-response type and the lower passband edge in artifacts in non-causal filtering.

0.16 Hz 0.2 Hz 0.3 Hz

FIR

IIR



Using MNE in Python [10], we examined the effect of impulse-response type (**FIR vs. IIR**) and lower passband edge (**0.16 vs. 0.2 vs. 0.3 Hz**), while holding the upper passband edge constant at 30 Hz and using a 200ms pre-stimulus baseline correction. Zero-phase was achieved by forward-backward filtering.

Hierarchical modeling of filter and experimental effects

To examine the interaction between filter and experimental manipulation, we used linear mixed-effects models [11, 12] to model all effects simultaneously in the N400 window (see also [13]).

- The main effect for experimental manipulation remains significant.
- There is a main effect for passband.
- There is a main effect for impulse-response type.
- There is no interaction between impulse-response type, passband and experimental manipulation, either pairwise or all together.

Effect	χ^2	df	$\Pr(>\chi^2)$
lateral	16.98	2	< 0.001
manipulation	497.57	1	< 0.001
response type	5.34	1	0.0209
passband	13.04	2	0.0015
lateral:manipulation	71.66	2	< 0.001
lateral:response type	1.27	2	0.5307
manipulation:response type	0.01	1	0.9084
lateral:passband	1.38	4	0.8473
manipulation:passband	0.63	2	0.7302
response type:passband	2.62	2	0.2695
manipulation:response type:passband	0.72	2	0.6983

Conclusion

The selection of an appropriate filter must be an informed choice for the experimental design in question.

There is no one-size-fits all in convolution (filtering, baseline correction, averaging, etc.).[7, 14, 15]

There are biphasic ERP responses independent of filter effects.

The different ERP patterns observed across languages cannot be reduced to differences in filtering practices across laboratories.

Literature

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