Effects of Stimulus Type and of Error-Correcting Code Design on BCI Speller Performance

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Summary

The Farwell-Donchin speller is a brain-computer interface system in which the user watches the letter he wants to choose, and a temporal sequence of stimulus events at that location produces a corresponding sequence of event-related potentials in the EEG, which we then decode.

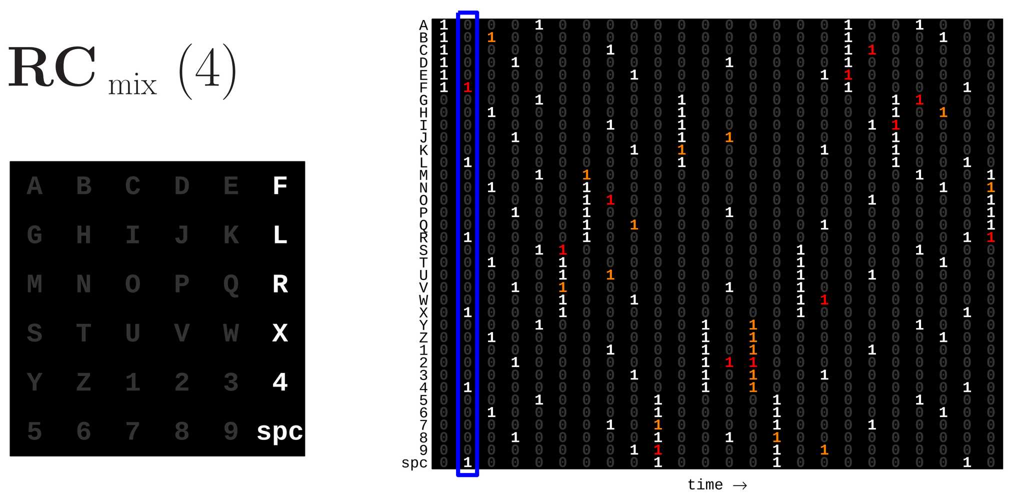
1. BCI performance may be affected:
   - positively by increased Hamming distances between sequences (exploiting the greater error-correction properties of better codes);
   - negatively by an increased number of short target-to-target intervals (TTI);
   - in some way that we do not fully understand, by the spatial arrangement of the stimuli.
2. Physical stimulus properties interact with the TTI and spatial effects.
   - For example, our apparent-motion "flip" stimulus reduces both effects.
   - Why? Stronger primary visual cortex responses? So far we've found no positive evidence for this from EEG scalp maps...
   - The net result is an overall improvement, and a particular advantage for codes with better error correction.

Experimental Methods

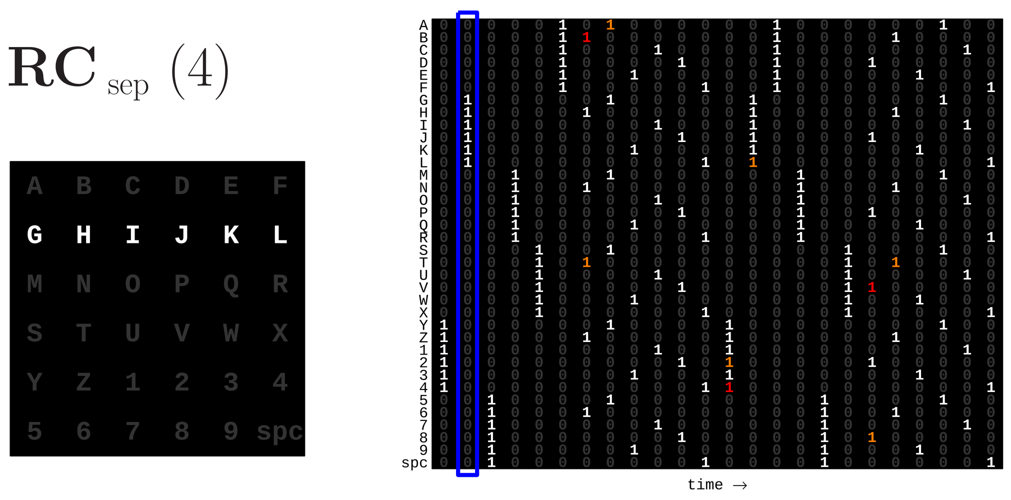
- 6 healthy subjects
- 16 blocks per subject, with block-by-block alternation between the traditional "flash" stimulus and our apparent-motion "flip" stimulus
- 20 trials (different letters to focus on) per block, with our 5 different codebook conditions interleaved randomly from trial to trial
- 72 stimulus events (potential "bits") per trial
- 167 msec stimulus onset asynchrony (one stimulus event to the next)
- 58-channel EEG acquired at 256Hz
- online BCI performance verified briefly at the end of the experiment (90%–100% correct)
- performance evaluated using offline (leave-one-letter-out) prediction analysis

Our experiment explored the following 5 different codebooks (minimum Hamming distances per 24 bits are given in parentheses). In nearly all the literature so far, only **RC**$_{sep}$ and **RC**$_{mix}$ have been considered.

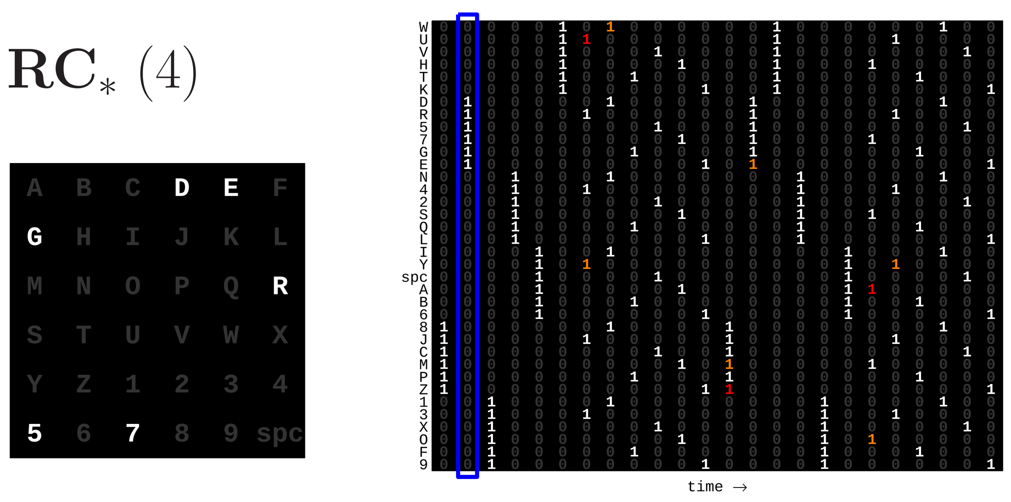
RC$_{mix}$ (4)



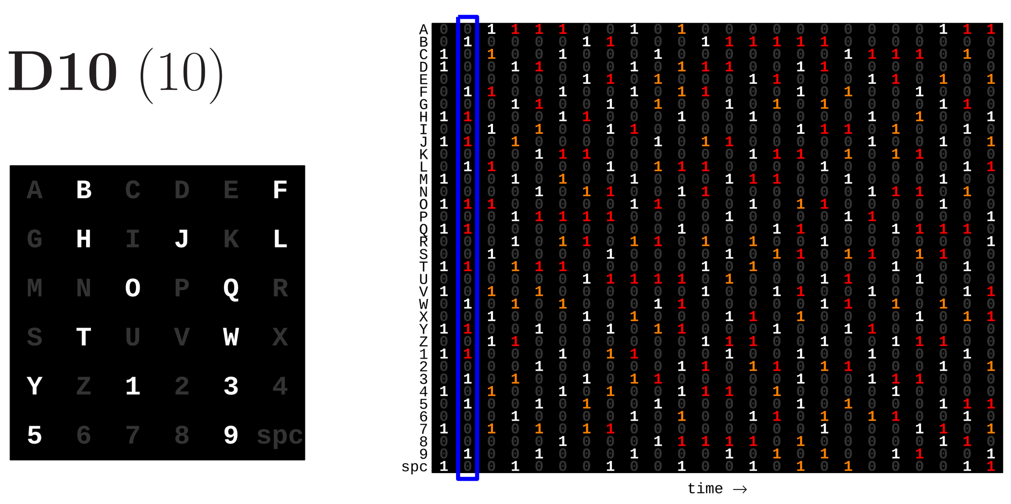
RC$_{sep}$ (4)



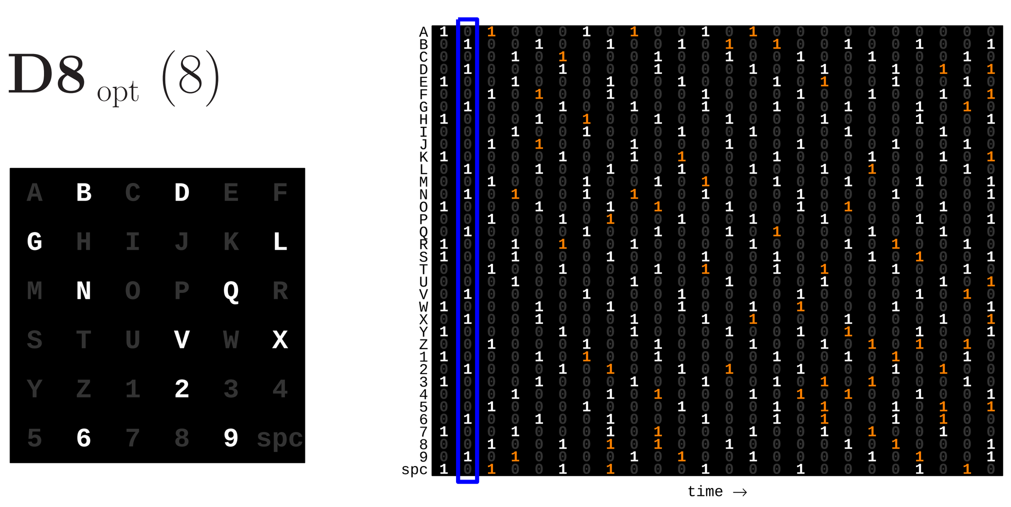
RC$_{*}$ (4)



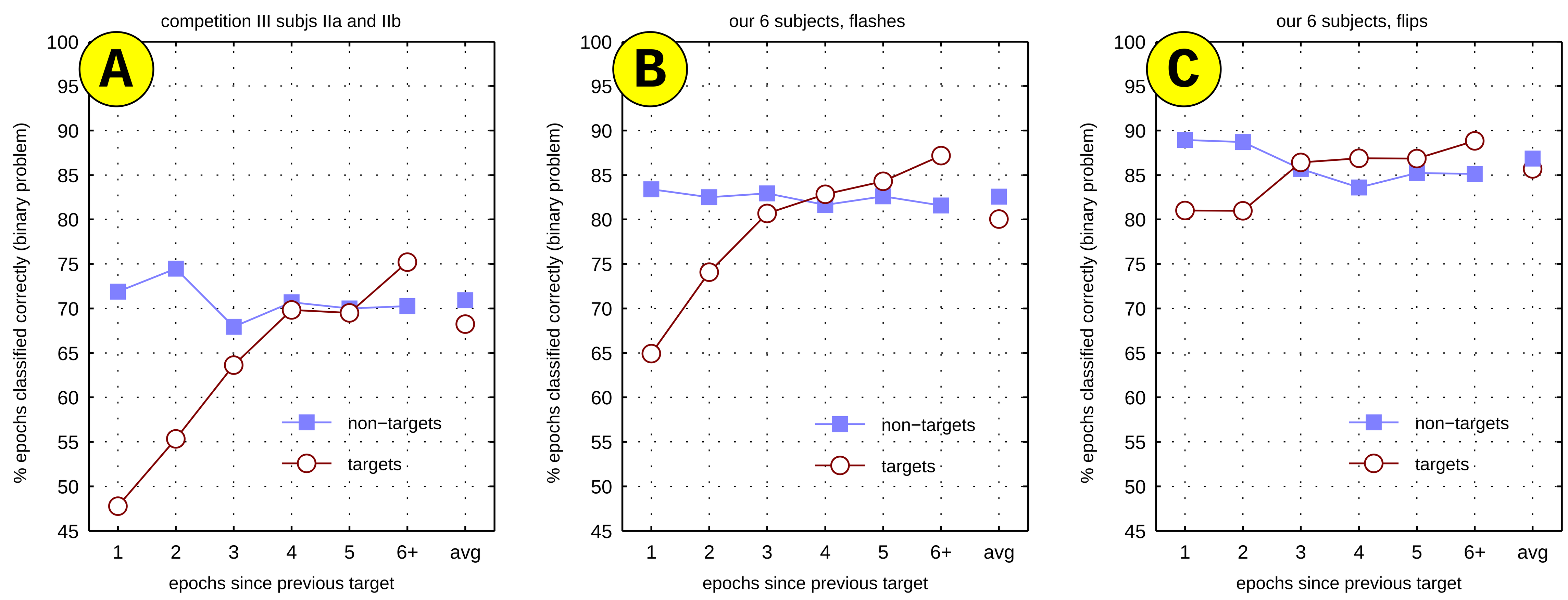
D10 (10)



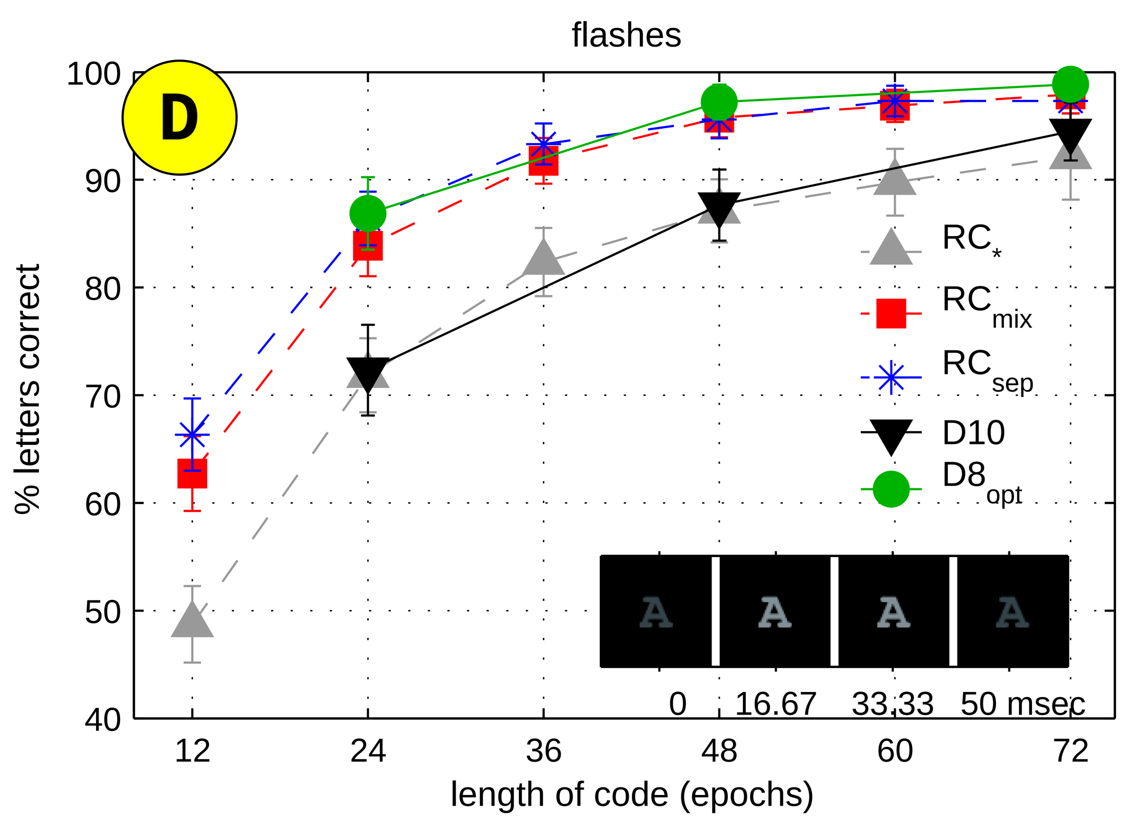
D8$_{opt}$ (8)

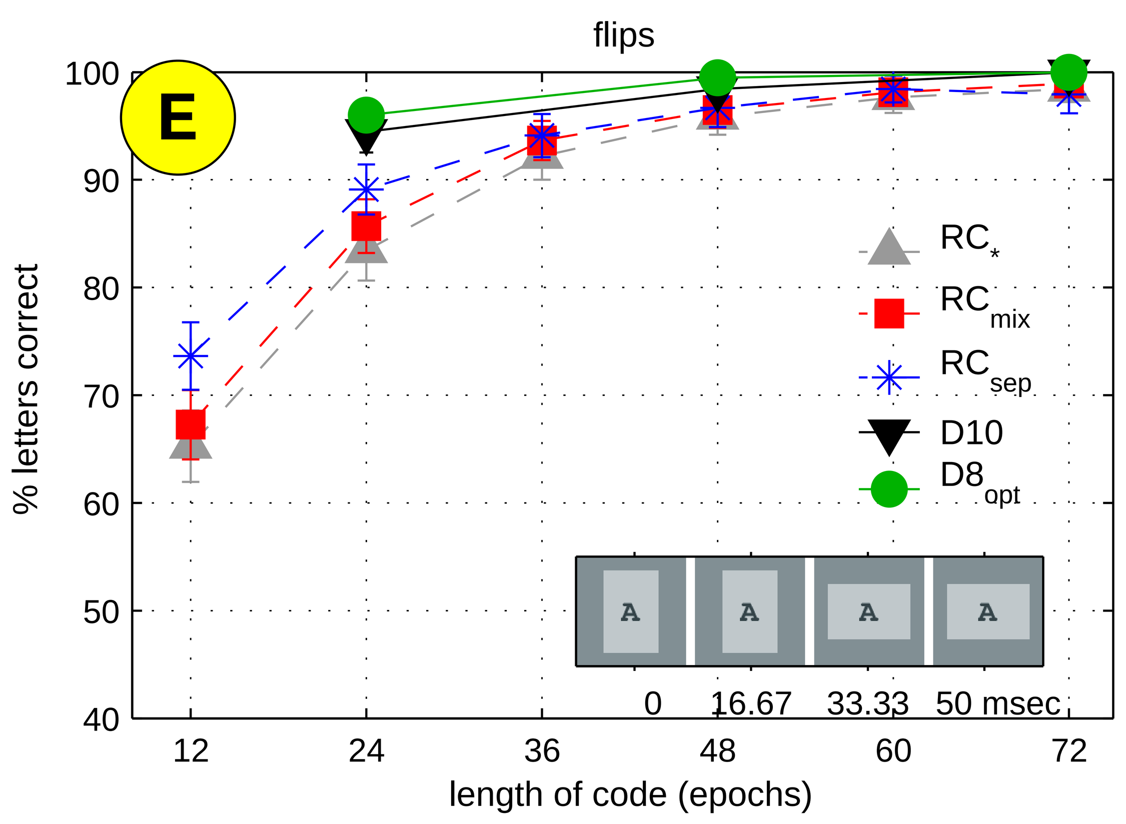


You might think that decoding accuracy should increase if Hamming distances are increased But this comes at the cost of decreased target-to-target intervals (TTI): red '1' marks TTI=1, orange marks TTI=2. Short TTIs may be a problem, since they lead to weaker brain responses: this is confirmed in figures A and B:



Indeed, short TTIs seem to lead to poor letter accuracy for **D10** (compare black with red/blue in figure D).





D8$_{opt}$ was the result of our optimization of the tradeoff between these two considerations. Despite its smaller Hamming distances, it certainly beat **D10** (compare green with black in figure D). But it only "broke even" with respect to the traditional RC codes (compare green with red/blue in D). Why? Well, our optimization did not consider psychophysiological effects of the codebook's *spatial* properties (the difference between **RC**$_{sep}$ and **RC**$_{*}$). It seems that these can also make a big difference (compare grey with red/blue in figure D). So, one future option would be to take *this* into account too.

However, we have one further twist. Traditionally the stimulus event is a "flash" (grey letters briefly turn white). But we had previously found that subjects performed better with an apparent-motion "flip". We find that this stimulus suffers a much smaller short-TTI disadvantage (compare figures B and C) and also a smaller spatial-disruption disadvantage (compare grey with red/blue in E). The result is that both error-correcting codes (**D8**$_{opt}$ and **D10**) perform better than the RC codes (compare black/green with the rest in E). In fact, **D8**$_{opt}$ together with the "flip" stimulus gives us the best performance over all.