# RUNNING HEAD: Visual processing at goal and effector locations during motor preparation

**Visual processing at goal and effector locations is dynamically enhanced during motor preparation**

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# Abstract

Previous theoretical and experimental works has shown that preparing to act causes enhanced perceptual processing at movement-relevant locations. Up until now, this has focused almost exclusively on the goal of an action, neglecting the role of the effector. We addressed this by measuring changes in visual processing across time during motor preparation at both goal and effector locations.

We compared event related potentials (ERPs) elicited by task-irrelevant visual probe stimuli at both goal and effector locations during motor preparation. Participants were instructed to place their hands on two starting positions (effector locations) and an auditory tone instructed them to immediately move to one of two target buttons (goal locations). Probe stimuli were presented in the interval between the offset of the cue and the execution of the movement at either a goal or an effector location. Probes were presented randomly at either 100ms, 200ms or 300ms after the auditory cue.

Analysis of the visual N1 ERP showed enhanced visual processing at moving vs. not-moving goal locations across all three SOAs. At effector locations, enhanced processing for the moving vs. not-moving effector was only observed during the middle (200ms) SOA.

These results demonstrate, for the first time, simultaneous perceptual enhancement of goal and effector locations during motor preparation. We interpret these results as reflecting a temporally and spatially specific dynamic attentional map of the environment that adapts to maximise efficiency of movement by selectively weighting processing of multiple functional components of action in parallel.

# 1. Introduction

To interact effectively with the physical environment requires us to plan action as efficiently as possible. The importance of accurate and effective action is reflected in the fact that motor preparation has effects on cognitive processes other than the purely motoric. One such process that has been well studied is visual perception, which is enhanced in a spatially selective manner by an intention to perform a goal directed action. This enhancement can be measured using behavioural, electrophysiological or other neuroimaging measures of visual processing, and allows us to make inferences about the underlying stages of motor processing that cause it, for example by comparing visual processing at locations involved in action with those that are not.

Whilst this approach has consistently demonstrated perceptual enhancement at the location of the goal of action, the influence of motor preparation on visual perception near the effector has been comparatively neglected. This has led to a situation whereby very little work has systematically addressed the influence of the effector location in action planning in human participants (though see Eimer, Forster, Van Velzen, J, & Prabhu, 2005; Forster & Eimer, 2007; Juravle & Deubel, 2009; and Juravle, Deubel, & Spence, 2011 for somatosensory processing on the hand), which in turn has led to potentially simplistic modelling of the effects of movement preparation on sensory processing with an undue focus on goal locations.

The Premotor Theory of Attention (Rizzolatti, Riggio, Dascola, & Umiltá, 1987; Rizzolatti, Riggio, & Sheliga, 1994) and the Visual Attention Model (Schneider, 1995) provide frameworks for understanding the perceptual consequences of action preparation. The Premotor Theory predicts that space is represented in the brain by effector-specific “spatial pragmatic maps” in the parietal cortex (Rizzolatti et al., 1994, p. 231), responsible both for the perception of space and for the planning of action. An intention to act upon a particular area of space causes a motor program to be set up within an effector-specific map, and until it is executed the activity of neural populations that code for the perception of that area of space is facilitated. Whilst the theory maintains that spatial attention arises from facilitation associated with the preparation of goal-directed *action*, it does not explicitly limit the scope of this facilitation to goal *locations*, and the principles it establishes could equally well be expected to apply to any action-relevant locations in space, such as those of the effector.

The majority of experimental tasks used to study the perceptual consequences of an intention to act were developed to investigate the programming of saccades. The effects on perception of preparing to make a saccade are remarkably similar to those seen in tasks that manipulate covert spatial attention; discrimination and detection of visual targets at the goal of a saccade are facilitated (Hoffman & Subramaniam, 1995; Posner, 1980; Rizzolatti et al., 1987; Schneider & Deubel, 1995; Shepherd, Findlay, & Hockey, 1986). Consistent with these behavioural observations, electrophysiological work has shown enhanced activity in extrastriate visual areas when stimuli were presented at goal locations during saccade preparation (Eimer, Van Velzen, Gherri, & Press, 2006), effects highly reminiscent of those observed in tasks involving cued spatial attention (e.g. Mangun & Buck, 1998). Similar approaches have more recently been applied to manual movements. Enhanced processing at goal locations has been demonstrated during the preparation of pointing (Baldauf & Deubel, 2008b; Deubel, Schneider, & Paprotta, 1998), reaching (Baldauf & Deubel, 2008a; Baldauf, Wolf, & Deubel, 2006) and grasping (Gilster, Hesse, & Deubel, 2012; Schiegg, Deubel, & Schneider, 2003) movements.

Further, lateralisation of event-related potentials (ERP) elicited in response to spatial cues that are thought to represent the operation of a frontoparietal attentional control network (ADAN, LDAP, Eimer & Van Velzen, 2002; Hopf & Mangun, 2000; Nobre, Sebestyen, & Miniussi, 2000) have been observed when shifting spatial attention (Eimer & Van Velzen, 2002; Van Velzen, Forster, & Eimer, 2002) but also when preparing saccades (Eimer, Van Velzen, Gherri, & Press, 2007; Gherri & Eimer, 2008; Wauschkuhn et al., 1998; Van der Lubbe, Neggers, Verleger, & Kenemans, 2006) and manual movements (Gherri & Eimer, 2010; Gherri, Van Velzen, & Eimer, 2007; Mathews, John, Dean, & Sterr, 2006; Praamstra, Boutsen, & Humphreys, 2005; Wascher & Verleger, 1997). These findings suggest shared sensorimotor control mechanisms involved in attentional orienting and in programming motor responses and are consistent with fMRI evidence showing a considerable overlap in activated brain regions during both types of task (Astafiev et al., 2003; Corbetta et al., 1998; Perry & Zeki, 2000).

Studies that have used measures of visual perception during goal directed action show that task instructions that emphasise either the goal or the effector can alter the balance of processing priorities between the two (Gherri, Van Velzen, & Eimer, 2009; Van Velzen, Gherri, & Eimer, 2006). Whilst this work shows that perceptual enhancement at the effector location can happen in principle, their pattern of results suggests that this effect may be limited to either goals *or* effectors, dependent upon top down factors such as task instructions. This interpretation is inconsistent with findings that suggest that the coupling between action and perception at the goal location is obligatory (Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995; Schiegg et al., 2003; Schneider & Deubel, 1995, 2002, though see also Belopolsky & Theeuwes, 2009; Deubel, 2008; Hunt & Kingstone, 2003, for arguments to the contrary). A possible explanation may be found in terms of the time course of motor preparation: if the temporal sequence of goal and effector processing differs (perhaps due to differing underlying mechanisms, e.g. Cisek & Kalaska, 2010) then the discrepancies in terms of enhancement at goal and effector locations in previous studies may be due to perceptual processing being measured at a point in time when *either* goal *or* effector processing is occurring, thus ‘missing’ the perceptual enhancement of the other component of action.

Making use of the excellent temporal resolution of event-related potentials (ERPs), electrophysiological studies into effects of movement preparation on visual processing typically use a delayed response paradigm. In this approach the participant receives instruction from two separate symbolic cues, the first (S1) instructing them which location to prepare a movement toward; and the second (S2) instructing them to actually execute it (or in some cases to withhold execution). Task irrelevant probe stimuli are presented in the delay between the two. The advantage of this method is that it allows temporal separation of movement preparation and the concomitant effect on sensory processing, but a disadvantage is that the delay causes the participant to be in a somewhat artificial state of anticipation, having planned an action but waiting to execute it. In contrast, most behavioural studies have used immediate response paradigms in which one cue instructs the participants where to move and also serves as a signal to execute the movement. However these designs require participants to make a response to probe stimuli, thus introducing a secondary task and reducing ecological validity.

In the present study we made use of the strengths of both approaches to investigate the interaction between action planning and visual processing at both the goal and the effector location during movement preparation. To achieve this we used the amplitude of the N1 component of the visual ERP as an index of extrastriate cortical activity in response to task-irrelevant visual probe stimuli presented at effector and goal locations. Unlike previous ERP studies that used a delayed-response paradigm, our participants executed a reaching movement as soon as a cue instructed them where to move, allowing us to measure the neural correlates of action planning on perception in a temporally sensitive manner. By assessing perceptual processing at multiple time points we were able to investigate whether the effects on visual processing at goals and effectors is specific to each location, and whether such processing can occur in parallel.

# 2. Method

## 2.1 Participants

A sample of 14 participants (12 females) took part in the experiment after giving informed consent. Some were paid in cash, and some received course credit as payment for participation. Participants ranged in age from 19 to 29 (mean age was 23.4 years), all were right handed by self report, had normal or corrected-to-normal vision and none had been diagnosed with any movement disorders. One participant was excluded from ERP analyses due to excessive eye movements, leaving a total of 13 participants. The study was approved by Goldsmiths’ ethics committee and informed consent was obtained from all participants.

## 2.2 Apparatus

The experiment was conducted on a movement console which consisted of a gently sloped surface with a separate haptically-defined starting position for the left and right hand nearest to the participant, and separate goal buttons for the left and right hand, measuring 4 cm in diameter, located directly in front of the starting position, at a distance of 23 cm from the starting position. Starting positions and goal buttons were positioned at 18 cm from the body midline on either side.

A one-way mirror was positioned above the console, between it and the participant, above whom was a 21” CRT computer monitor with the screen facing down. The mirror was adjusted such that when the display from the monitor was reflected on the glass, it appeared to originate from the console below. Stimuli could thus be presented so that they appeared to be projected directly onto the surface where movement took place, without being obscured by each participant’s hand. By dimming the ambient light in the testing cubicle, the mirror reflected the light from the monitor above, whilst preventing light from the movement surface below from passing through, thus allowing a participant to move his or her hand without having visual access to its location.

Circular stimuli, of the same diameter as the buttons at the goal locations were visible throughout the experiment, at the both the goal and effector locations.

## 2.3 Procedure and stimuli

The sequence of events is illustrated in Figure 2. Participants sat in front of the movement console in a dimly lit cubicle, with their gaze on a fixation cross presented centrally, equidistant between the starting position and the goal, and the topmost part of the fingers of each hand resting on the starting position. They were asked to maintain their gaze on the fixation cross through each block. In order to prevent vision of the hand biasing our comparisons between effector and goal locations, participants’ hands were occluded behind a one-way mirror. At the start of each trial, an auditory cue sounded for a duration of 100ms, comprised of a tone of either 1000 Hz or 1500 Hz indicating which target button to press. The pitch to target mapping of the cue was counterbalanced across participants, who were instructed either to move their left hand to the left button, or their right hand to the right button, immediately after hearing it. A total of 1440 trials were presented across ten blocks, with a break in between each block. The duration of the experimental session was approximately one and a half hours.

A task-irrelevant visual ‘dot probe’ presented in the centre of one of the circle stimuli was used to measure visual processing; Following the cue, after an SOA of 100, 200 or 300 ms (chosen based upon both previously published behavioural work, e.g. Schiegg et al, 2003, and pilot data), a small white circle, measuring 2º visual angle was presented via the monitor, but which appeared to originate on the movement console. This probe stimulus was presented for 100 ms equi-probably but pseudo-randomly at either one of the goal or one of the effector locations.

Participants received immediate auditory feedback if the incorrect target button was depressed, in which case a buzzer sounded and the trial was discarded. After pressing one of the two goal buttons, participants returned their hands to the starting position, which signalled the end of a trial. After a random inter-trial interval of between 500 and 1000ms the next trial started.

<FIGURE 1 HERE>

## 2.4 Data Analysis

### Behavioural Analysis

Movement time and accuracy were recorded on a trial by trial basis, and separate averages were computed for each participant, for each component of action *(goal, effector)* and each of the two variables *probe location* (*movement-relevant, movement-irrelevant*), and *SOA* (*100, 200, 300ms*). These were analysed with repeated measures ANOVAs, with all post-hoc t-tests Bonferroni corrected.

### EEG recording and data analysis

The EEG was filtered at a rate of 0.1 – 40 Hz using a band-pass filter, and segmented into 800ms epochs, running from 400ms before the presentation of the auditory cue to 400ms after. Epochs were averaged relative to a baseline period 100ms before the onset of the auditory cue. Trials with eye blinks or movements (voltage in HEOG channels exceeding +/- 30 µV) or muscle artefacts (voltage at any other electrode site exceeding +/- 80 µV) were discarded.

Effects of movement preparation on sensory processing will be studied by examining modulations on the posterior ERP component N1 at P7/P8 and PO7/PO8, representing visual processing in secondary visual areas (e.g., Hillyard & Anllo-Vento, 1998). Mean ERP amplitudes were analysed for 40ms latency windows centred around the peak of the N1 component at electrodes P7, P8, PO7 and PO8 (interval tested for probe at: goal, 188-228ms, effector, 175-215 ms). Information about the visual hemifield of probe presentation, and the brain hemisphere over which ERP responses were measured was collapsed to indicate whether the response was contralateral or ipsilateral to the side of presentation. Separate ANOVAs were performed for probes presented at goal and effector locations, using three within-subject factors: *probe location* (probes either presented on the effector that was about to move versus on the effector that was not, or on the goal that was about to be moved toward versus on the goal that was not), *SOA* (100/200/300 ms) and *hemisphere* (contralateral/ipsilateral to probe location). All results were corrected for violations of sphericity using the Greenhouse-Geisser method where appropriate, and all post-hoc t-tests were Bonferroni corrected.

Where ERPs are presented visually they are plotted relative to the onset of the visual probe. Due to three different SOAs being used, the relative timing of the cue onset and thus the baseline differs depending on probe timing. Where ERPs are presented collapsed over the variable SOA, the baselines plotted represent an averaging of 100ms baseline calculations taken across the three time windows.

# 3. Results

## 3.1 Behavioural measures

Behavioural measures of reaction time and reaching accuracy were recorded. Trials with RTs longer than 1500ms or shorter than 400ms (3.9%) were discarded. The mean time from cue onset to reaching the target was 825 ms (SD=210ms), 826 ms (SD=218 ms) and 825 ms (SD=217 ms) for the 100, 200 and 300 SOA conditions respectively. The mean accuracy rate for the three SOA conditions was 99.8% (SD=3.81%), 99.7% (SD=14.8%) and 99.2% (SD=8.81%).

Movements to the goal upon which the probe was presented were both more accurate than those to the un-probed goal, F(1,12)=9.628, p=.009, and also faster toward the probed than the unprobed goal, F(34.164), p<.001. *Probe location* interacted with *SOA* for movement times, F(2,24)=31.509, p<.001. Post-hoc t-tests compared RTs for probed and un-probed goal trials, separately for each SOA. RTs were shorter for trials in which the goal was probed at 100 ms, t(12)=8.209, p<.003, 200 ms, t(12)=2.939, p=.036, and 300 ms, t(12)=2.615, p=.069.

Movements executed using the effector that was probed were more accurate than those using an un-probed effector, F(1,12)=8.540, p=.013; they were also faster, F(1,12)=23.825, p<.001. *Probe location* interacted with *SOA* for movement times, F(2,24)=7.398, p=.003. Post-hoc t-tests compared movement times using the probed and the un-probed effector separately for each SOA. Trials in which the probe was presented at 100 ms were faster when using the probed vs the un-probed effect, t(12)=5.885, p<.003, but not at 200 or 300 ms.

## 3.2 Electrophysiological results

Figures 2 and 3 show the ERPs elicited by task-irrelevant visual probes presented at the goal and effector locations respectively. Bold black lines represent ERPs elicited by probes presented at a movement relevant location, grey lines show ERPs elicited by probes presented at locations that were not relevant to the movement. The task-irrelevant visual probe stimuli elicited clear visual N1 ERP components that were maximal at electrode sites P7/8 and PO7/8 over the hemisphere contralateral to the side of presentation (see Figure 2) . The location at which the probe was presented had a clear effect on the amplitude of the N1 component: N1 components show enlarged amplitudes when the probe was presented at a location relevant to the movement that was being prepared and this was most pronounced over the contralateral scalp. Crucially, whereas clear modulations can be observed for all SOAs when the probe was presented near the goal of an upcoming movement, when the probe was presented near the effector this seemed to depend on the time between the movement cue and the probe onset (SOA) and was most pronounced for the 200 ms SOA.

These informal observations were substantiated by statistical analysis of the N1 mean amplitude, carried out separately for probes presented at goal and effector locations using the variables *probe location*, *SOA* and *hemisphere*.

<FIGURES 2 AND 3 HERE>

### ERP measures of visual processing at the goal.

The observed lateralised nature of the visual N1 was confirmed by a main effect of *hemisphere* (F(1,12)=12.777, p=.004, ηp2=.516). The observation that the N1 amplitude elicited by probes that were presented close to the goal of the movement was enhanced, and more strongly so over the contralateral hemisphere, was confirmed by a *probe location* by *hemisphere* interaction *(*F(1,12)=11.339, p=.006, ηp2=.486), while a main effect of probe location was not observed (F(1,12)=.2-4, p=.803, ηp2=.005). Post-hoc t-tests showed that the N1 amplitude elicited by probes presented at the movement goal was larger than for probes presented at the goal that was not being moved to when measured over the contralateral hemisphere, t(12)=-4.345, p=.002, d=.180. This effect was not significant when measured over the ipsilateral hemisphere, t(12)=1.922, p=.158, d=.533.The main effect of *SOA* was not significant, F(2,24)=1.881, p=.174, ηp2=.136, and nor did it interact with any other variables, all F(2,24)<.347, all p > .690, all ηp2<.030.

### ERP measures of visual processing at the effector

Figure 3 shows an enhanced N1 component when the probe was presented near the effector that was used to make the movement, and that this was more pronounced at contralateral electrodes. This was reflected in a *probe location* by *hemisphere* interaction (F(1,16)=15.686, p=.002, ηp2=.567), in the absence of a main effect of *probe location* (F(1,12)=.402, p=.538, ηp2=.032). The lateralised nature of the visual N1 was again reflected by a significant main effect of *hemisphere*, F(12)=32.290, p<.001, ηp2=.729. Post-hoc t-tests showed that probes presented on the moving effector were larger than those on the effector that was not moving when measured over the contralateral, t(12)=-3.353, p=.012, d=.396, but not the ipsilateral hemisphere, t(12)=1.387, p=.382, d=.385.

The observation that N1 modulations were dependent on SOA for effector probes was confirmed by a *probe location* by *SOA interaction (*F(2,24)=3.940, p=.047, ηp2=.225). Over the contralateral hemisphere, probes presented on the moving effector elicited larger N1s than those on the effector that was not moving at the 200 ms SOA (t(12)=-4.366, p=.003, d=.826) but not at the 100 or 300 ms SOAs, both t(12)>-1.195, both p > .255, both d<.331.

## 4. Discussion

We used ERP measures of visual processing to investigate the effect of action preparation on perception during a manual reaching task, separately at both the location of the goal of the movement, and the location of the effector used to execute it. We used an immediate-response paradigm whilst recording participants’ EEG as they performed the reaching task. Task-irrelevant visual probe stimuli were presented on the movement space, and the amplitude of the neural response to these probes was used to measure visual processing at the goal and the effector, at three different cue-probe SOAs (100, 200 and 300ms post cue-onset).

Our results show, for the first time, simultaneous enhancement of visual processing at both goal and effector locations, suggesting that both are important functional components of movement. Goal locations showed enhanced visual processing at all SOAs, suggesting that processing of the goal was modulated early in the course of motor preparation, and sustained throughout. Enhancement of effector locations, on the other hand, was only evident at the 200ms SOA, suggesting a more temporally specific process, delayed relative to the goal, and completed by 300ms.

This temporal pattern rules out a very basic interpretation of these results, namely that motor preparation leads to the perceptual enhancement of an entire visual hemifield. In our experimental paradigm, goal and effector locations were always on the same side of space relative to the participant (movements were always made straight ahead, away from the body, and did not cross the midline). If our ERP results had shown that changes to visual processing at goal and effector locations did not differ according to SOA, they could be explained by an entire visual hemifield receiving enhanced processing. The temporal differences that we show across SOAs negate this possibility, and we can with confidence state that the changes in visual processing that we report have high specificity to goals and effectors.

These results also suggest that, at the very least, the effects on perception of motor preparation do not appear to reflect an underlying serial process that first enhances the location of one component of movement (e.g., the goal) and then moves on to the next component (e.g., the effector). If this were the case, we would expect the pattern of enhanced processing across SOAs to switch between the goal and effector, instead of remaining constant at both locations during the 200ms SOA. Behavioural work has shown that action-induced enhanced processing can occur in parallel at multiple goal locations during the preparation both of sequences of manual movements (Baldauf & Deubel, 2008a; Baldauf et al., 2006), and of independent hand and eye movements (Jonikaitis & Deubel, 2011). Our results extend this finding of parallel processing from within multiple instances of one component of movement – goal locations – to between functional components, such as a goal and an effector. Whether these components are subject to the same or separate underlying motoric processes in posterior parietal cortex (e.g. Buneo & Andersen, 2006; Cisek & Kalaska, 2010) is an open question, since the effects on visual processing that we show here happen downstream of such activity. However it seems likely that, given the clear functional differences between goals and effectors in the context of a movement plan, these differences in visual processing are reflective of qualitatively different underlying mechanisms.

Previous work (Gherri, Van Velzen, & Eimer, 2009) has shown that task instructions can, by emphasising either the goal or the effector, bias processing to one component of movement or the other. It is the case that any instruction related to a manual movement must to some extent implicitly bias the participant toward the goal, since by definition the goal location is the target of the movement, and - however carefully task instructions are relayed so as to avoid bias - will always receive some linguistic emphasis. Whilst we cannot rule out the possibility that such a process is one factor influencing the effects we report, the observation of simultaneous enhancement of goal and effector locations at the 200ms SOA cannot be explained by reference to the influence of task instructions.

The observed effects on visual processing at the location of the goal are consistent with the predictions of the Premotor Theory (Rizzolatti et al., 1994), and the Visual Attention Model (Schneider, 1995). The pattern of results at the location of the effector was similar to that at the goal, but not identical. Any influence of the effector on changes to visual processing during motor preparation is not explicitly addressed by extant theories of action planning, and whilst previous work has shown enhancement at the goal *or* at the effector (Gherri et al., 2009; Juravle & Deubel, 2009; Van Velzen et al., 2006), ours is the first demonstration of *simultaneous* enhancement of both locations.

Together with previous observations, the pattern of results that we present here suggest that, during preparation of a manual movement, a mechanism or set of mechanisms adaptively and flexibly modulate sensory processing in order to maximise how effectively we interact with the environment. These findings are in agreement with the findings and interpretation of (Baldauf & Deubel, 2010) in the sense that an intention to act appears to set up a pragmatic attentional field, comprised of ‘hot spots’ of facilitation that rise and fall over the time course of motor preparation, serving to modulate perception as required by the particular motoric processes that give rise to them.

Our results show this attentional field is not only comprised of the locations of the goals of action, but also of the effectors that will be used to execute action. By doing this we are able to move from a goal-centred conception of selection-for-action to a model in which additional functional components of movement weight the distribution of spatial attention in a way that fits better with our understanding of sensorimotor processing in the brain.

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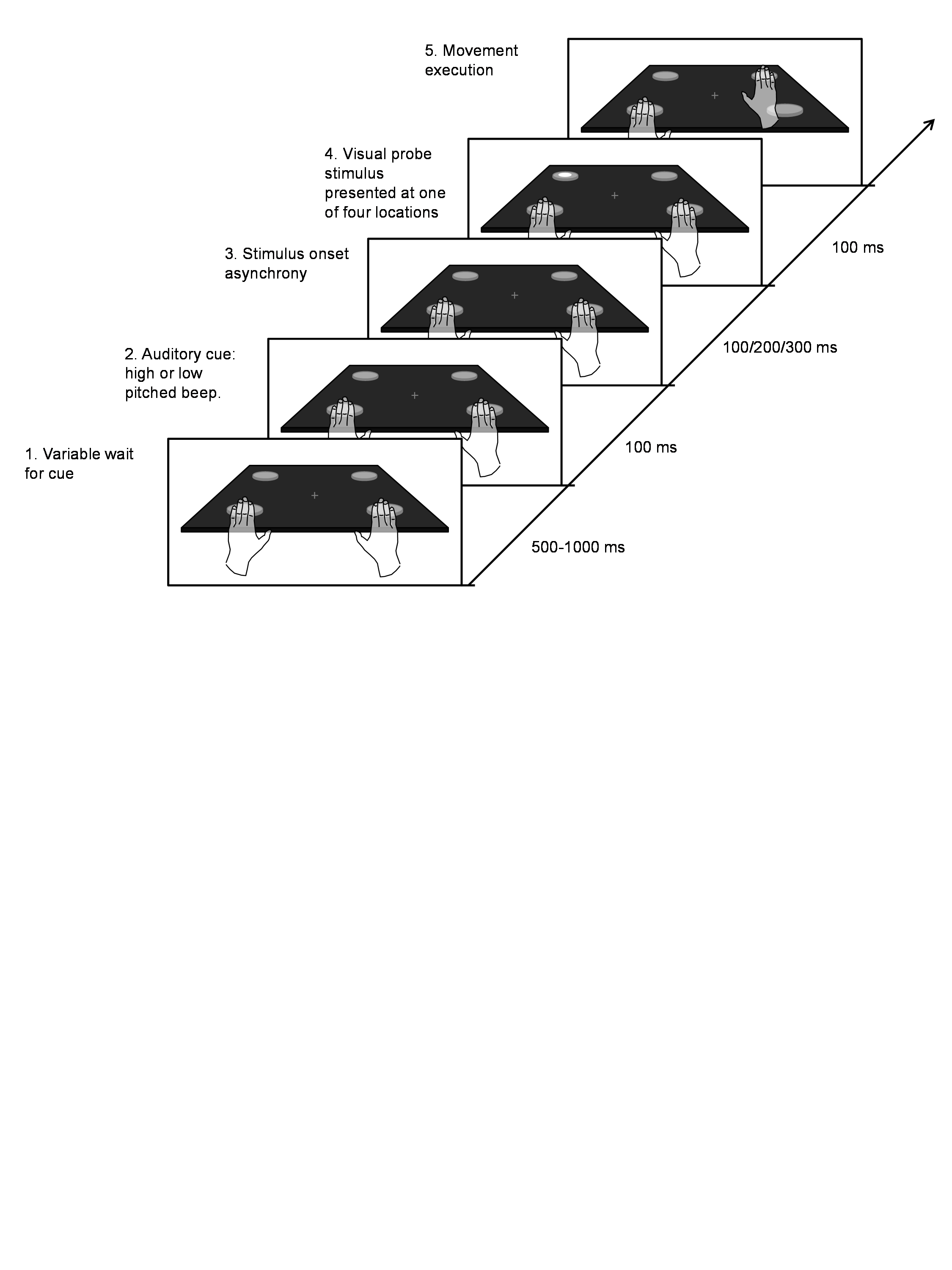
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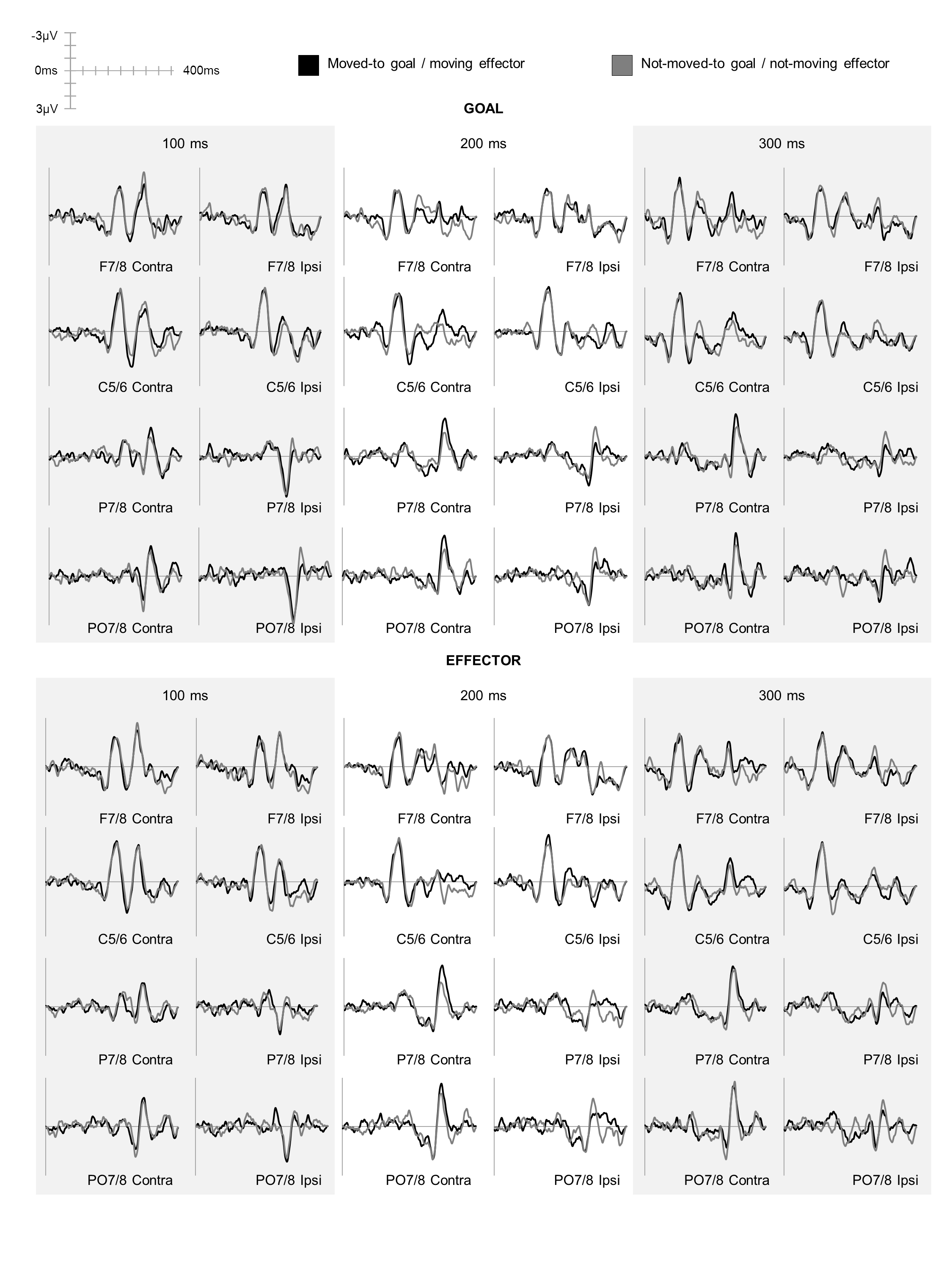
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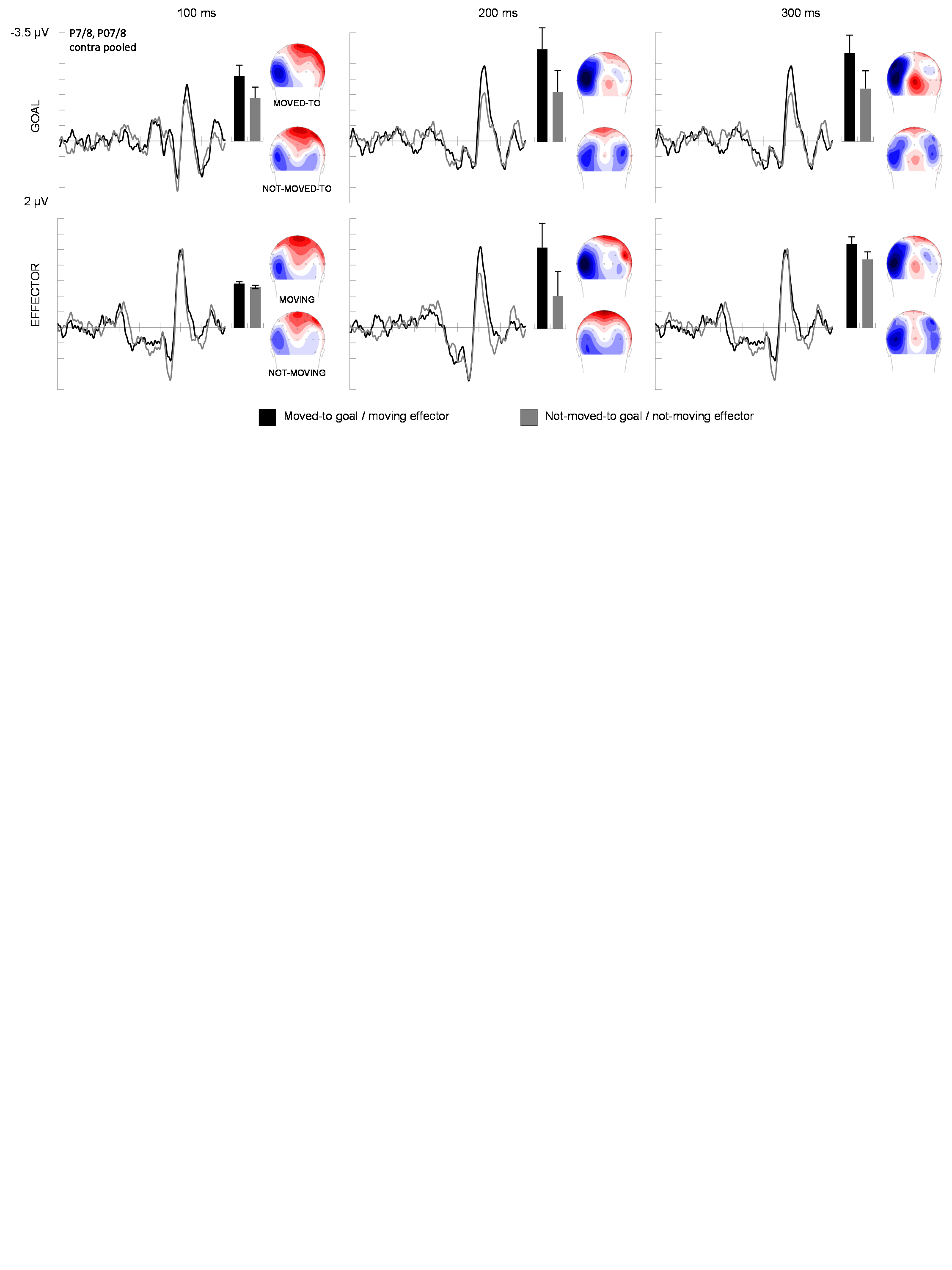
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## Figure 1. An illustration of the sequence of events during one trial.



**Figure 2. Grand average ERPs for probes presented at the probe (top panel) and effector (bottom panel) at each of the three SOAs (left column: 100ms, middle column: 200ms, right column: 200ms). Black lines are in response to probes on moved-to goals and moving effectors, grey lines are in response to not-moved-to goals and not-moving effectors.**

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**Figure 3. Grand average ERPs, scalp maps and mean amplitudes of the N1 ERP over pooled electrodes P7/8 and PO7/8, for probes presented at the goal (top row) and effector (bottom row), at three different SOAs (left column: 100ms, middle column: 200ms, right column: 300ms). Black lines are in response to probes on moved-to goals and moving effectors, grey lines are in response to not-moved-to goals and not-moving effectors.**