ウェブサイト公開用

(様式10)
(海外特別研究員事業)
令和 2年 3月 1日

海外特別研究員最終報告書

独立行政法人日本学術振興会 理事長 殿

採用年度 平成29年度
受付番号 15
氏 名 春日翔子
(氏名は必ず自署すること)

海外特別研究員としての派遣期間を終了しましたので、下記のとおり報告いたします。
なお、下記及び別紙記載の内容については相違ありません。

記

1. 用務地(派遣先国名) 用務地:クイーンズ大学 (国名: カナダ)

2. 研究課題名(和文) ※研究課題名は申請時のものと違わないように記載すること。
精緻な運動制御におけるボトムアップ感覚フィードバックの役割に関する研究

3. 派遣期間:平成 30年 2月 28日 ~ 令和 2年 2月 27日

4. 受入機関名及び部局名
Faculty of Health Sciences, Queen's University

5. 所期の目的の遂行状況及び成果…書式任意 書式任意(A4判相当3ページ以上、英語で記入も可)
(研究・調査実施状況及びその成果の発表・関係学会への参加状況等)
(注)「6. 研究発表」以降については様式10-別紙1~4に記入の上、併せて提出すること。

The purpose of this research is to clarify how sensory feedback of different modalities are integrated online, when we make fast body movements. The main sources of feedback motor control are vision and proprioception. Vision plays an important role to identify the location of the target (i.e., the goal of the movement), whereas vision and proprioception can both provide information about the position and motion of the body. However, it is unclear whether either one modality of the feedback information is exclusively utilized at a time, or both sources of information are incorporated in some way.

Previous research has shown that humans and animals integrate sensory feedback signals in a Bayesian manner; that is, estimation of the arm state is computed as a weighted sum of estimates from vision and proprioception, and sensory feedback information with less variance have a greater weighting. Proprioceptive feedback is often considered as noisier and less accurate than visual feedback. As a result, many of the previous studies suggested that contribution of vision was weighted more than proprioception in multimodal integration. However, even if visual feedback could be more accurate in major situations, it has a critical disadvantage as well. Our nervous system inherits transmission delay and it is much longer for vision than proprioception. For example, a previous study showed that if the arm is bumped by a mechanical load during movements, proprioceptive responses occurs in 25-60ms (Kurtzer et al., 2010; Nashed et al., 2012; Pruszynski et al., 2009), depending on how much complicated responses are required. On the contrary, responses to visual disturbances such as sudden virtual shift of the goal target or the hand position are observed in 90-120 ms (Dimitriou et al., 2013; Yang et al., 2011). Since longer time delay results in accumulation of noise which significantly affects state estimation, visual feedback is less accurate in this case.

To further understand the problem of multisensory integration that has two critical factors, that is, noise and time delay, a group of researchers recently proposed a dynamic Bayesian model instead of traditional Bayesian model (Crevecoeur et al., 2016). The dynamic Bayesian model considers not only signal variance, but also sensory delays when computing the weighting of each feedback information. However, it is still not unclear how differences in sensory delays influence feedback control of the arm itself. Should you use the more accurate (vision) or the fastest (proprioceptive)? To answer this question, we performed an experiment to directly compare the influence of proprioceptive and visual feedback during online arm control. Specifically, we have examined how motor correction is altered depending on the presence/absence of proprioceptive and visual feedback.

[Experiment 1] In the first year of the project, by performing a behavioural experiment of arm motor control, we found that proprioceptive feedback trumped visual feedback for online control of the arm in the earlier phase of movements. Visual feedback influenced on motor correction 30-50 ms later than the correction following proprioceptive feedback. This is due to the delay in visual processing, which was supported by a dynamic Bayesian model considering variability and delays of different feedback modalities.

Thirteen neurologically healthy individuals participated in this study. The experiment was performed using the KINARM exoskeleton robotic device (BKIN Technologies Ltd., Kingston ON, Canada; Scott, 1999). Participants sat in a chair and KINARM maintained their arm in the horizontal plane. They viewed a virtual reality display through a half mirror that showed a white cursor indicating a right index fingertip position and visual targets in the same plane (Figure 1, left). A screen under the display prevented the participants from directly seeing their arms. Participants controlled the cursor by performing reaching movements from a starting position towards the target as quickly and straightly as possible. Electromyography (EMG) were recorded using bipolar surface electrodes from upper-limb muscles involved with flexion or extension at the elbow or shoulder: the posterior deltoid (DP), the lateral head of the triceps (TLAT), the brachioradialis (BR), and pectoralis major (PM).

When the participants were performing reaching movements, mechanical and/or visual perturbations were applied in random trials. On the trial type of mechanical perturbation, step torques were applied to the right arm. As a consequence, the hand was bumped away and subjects corrected movement so that they could come back to the original trajectory (Figure 1, blue line). To investigate the effect of visual feedback on proprioceptive responses, in half of the mechanical perturbation trials the cursor indicating the fingertip position was eliminated (Figure 1, red line). On the trial type of visual perturbation, participants were presented cursor positions following trajectories which mimicked trajectories when the participant's arm was mechanically perturbed (cursor shift perturbation; Figure 1, cyan line). We also developed a dynamic Bayesian model for reaching movements, which predicted the similar muscle responses in two mechanical perturbation conditions with or without visual feedback, but smaller and delayed correction response to the visual perturbation.

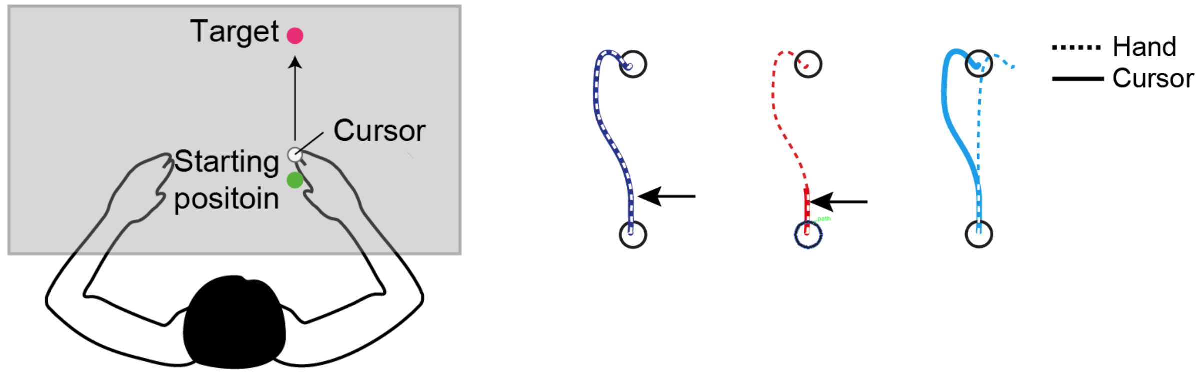

Figure 1. Experimental procedures. Left: a schematic picture of the experiment setup. Right: three trial types in Experiment 1. Blue lines indicate the trial type of mechanical perturbation with visual feedback and red lines indicate that without visual feedback. Solid lines indicate a cursor trajectory displayed on the monitor and dotted lines indicate a hand trajectory.

Motor correction nor muscle responses to mechanical perturbation was not different between the conditions with/without visual feedback (Figure 2). These results suggest that visual feedback does not take an effect on online control of the arm until considerably late time period. In other words, proprioceptive feedback dominates visual feedback in the rapid response of arm control during reaching movements.

On the contrary, visual perturbation trials showed clearly different patterns of motor correction and muscle responses. The peak amplitude of the muscle response was significantly smaller for the visual perturbation than the mechanical perturbation with visual feedback (Figure 2, lower panels). In addition, while muscle response to mechanical perturbation appeared at around 50 ms, muscle response to visual perturbation was first observed at around 90 ms. By performing a Receiver Operating Characteristic (ROC) analysis to determine when muscle activities were reliably different between the excitatory/inhibitory mechanical perturbations, we quantitatively showed that muscle responses for the visual perturbation were detected at 79-89 ms after perturbation onset in each muscle, whereas the responses for the mechanical perturbation were detected at 43-59 ms. While the difference in the latency did not reach a statistical significance ($P = 0.07$), muscle response was slower in visual perturbation for all muscles, which is assumed to be generated in a subcortical pathway. Overall, these results supported the prediction of the dynamic Bayesian model.

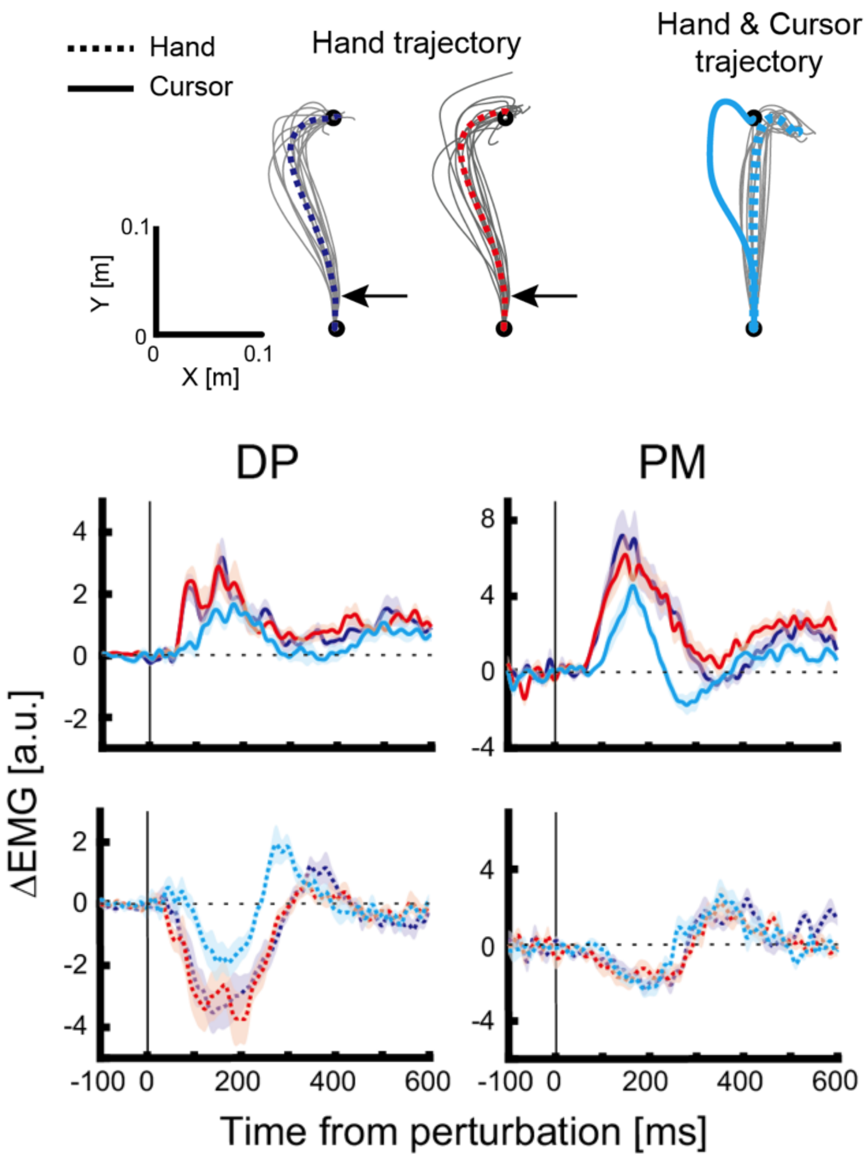

Figure 2. Motor correction and muscle responses for all participants in Experiment 1. Blue lines indicate the trial type of mechanical perturbation with visual feedback and red lines indicate that without visual feedback. Cyan lines indicate the trial type pf visual perturbation. Upper: individual (gray) and participants average (coloured and dotted) trajectories in each perturbation condition. Lower: muscle responses for perturbations. Solid lines show EMG activities observed when the targeted muscle was stretched (agonist perturbation) and dotted lines show EMG activities generated when the antagonist of the targeted muscle was stretched. Shaded area indicates ±1 SE.

[Experiment 2] In the second year of the project, to further explore the mechanism of multimodal integration, we asked how conflicts in visual and proprioceptive feedback resulted in rapid switching of motor responses initially reflecting the mechanical disturbance to a response that reflected visual feedback and the goal to reach the spatial target. Twelve participants participated in Experiment 2. The apparatus and general task procedure were same as Experiment 1. One of the two types of trial was exactly the same as the mechanical perturbation trials of Experiment 1, which provided both visual and proprioceptive feedback when mechanical perturbations were applied during reaching. We also tested a new type of trials in this experiment: trials provided both visual and proprioceptive feedback when mechanical perturbations were applied, and visual perturbations were applied at the same time (Figure 3). Notably, in these trials visual errors and proprioceptive errors conflicted with each other. We applied mechanical perturbations to the arm while

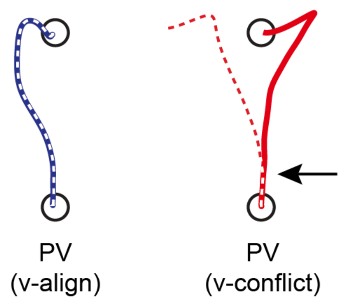

Figure 3. Two trial types of Experiment 2. Blue lines indicate the trial type of mechanical perturbation with the aligned visual feedback, and red lines indicate he trial type of mechanical perturbation with conflicting visual perturbation. Solid lines indicate a cursor trajectory displayed on the monitor and dotted lines indicate a hand trajectory.

the cursor shifted from the hand position at the same time, so that the lateral error in proprioceptive and visual feedback occurred in the opposite directions.

We found that in both trial types, the hand was bumped away by the mechanical load (black arrows in the Figure 4, upper panels) soon after the participant started reaching. However, trials in which the visual error occurred in the opposite direction to the mechanical perturbation halted the corrective response the peak hand displacement for the mechanical perturbation. As expected, muscle responses were initially similar whether visual feedback was aligned or in the opposite direction to the mechanical disturbance (Figure 4, lower panels). ROC analysis identified the time at which the muscle response for two trial types was differentiated at later than100 ms, suggesting that the first response when both proprioceptive and visual information is available reflects purely visual feedback process and multisensory occurs later.

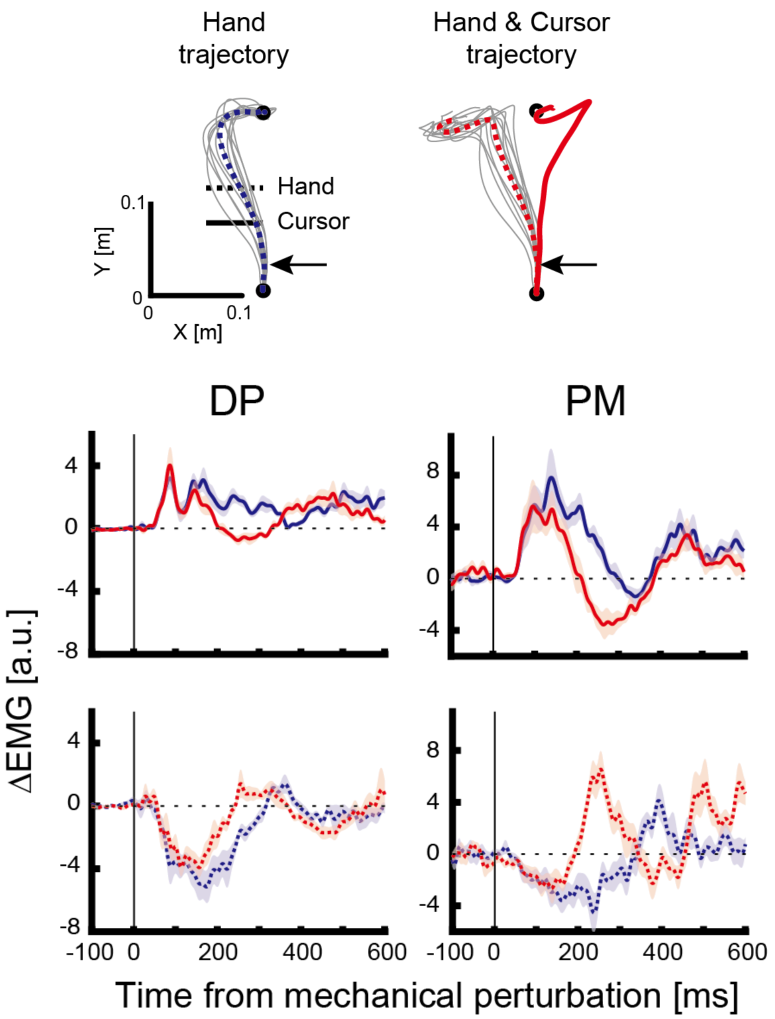

Figure 4. Motor correction and muscle responses for all participants in Experiment 2. Blue lines indicate the trial type of mechanical perturbation with aligned visual feedback and red lines indicate that with conflicting visual feedback. Upper: individual (gray) and participants average (coloured and dotted) trajectories in each perturbation condition. Lower: muscle responses for perturbations. Solid lines show EMG activities observed when the targeted muscle was stretched (agonist perturbation) and dotted lines show EMG activities generated when the

To summarize, the current study explored how proprioceptive and visual feedback of the limb interact during reaching. The first experiment tested how the presence of one or both sensory modalities influenced reaching and motor corrections with results compared to predictions based on optimal weighting of both sensory signals. The results highlight that the presence of visual feedback during a mechanical disturbance did not increase the size of the motor response but did decrease variance consistent with a dynamic Bayesian model. The second experiment highlighted how conflicts in visual and proprioceptive feedback resulted in rapid switching of motor responses initially reflecting the mechanical disturbance to a response that reflected visual feedback and the goal to reach the spatial goal.

Our result suggests that the brain correctly discriminate if the ongoing movement has been mechanically perturbed or visually perturbed, and then quickly calculate motor output that is needed to correct the movement. Such an elaborated mechanism to evaluate perturbation nature is demonstrated for the first time in the current study.