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Improving the real-time control of a non-invasive Brain-Machine Interface using a finite-state machine design

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Highlights

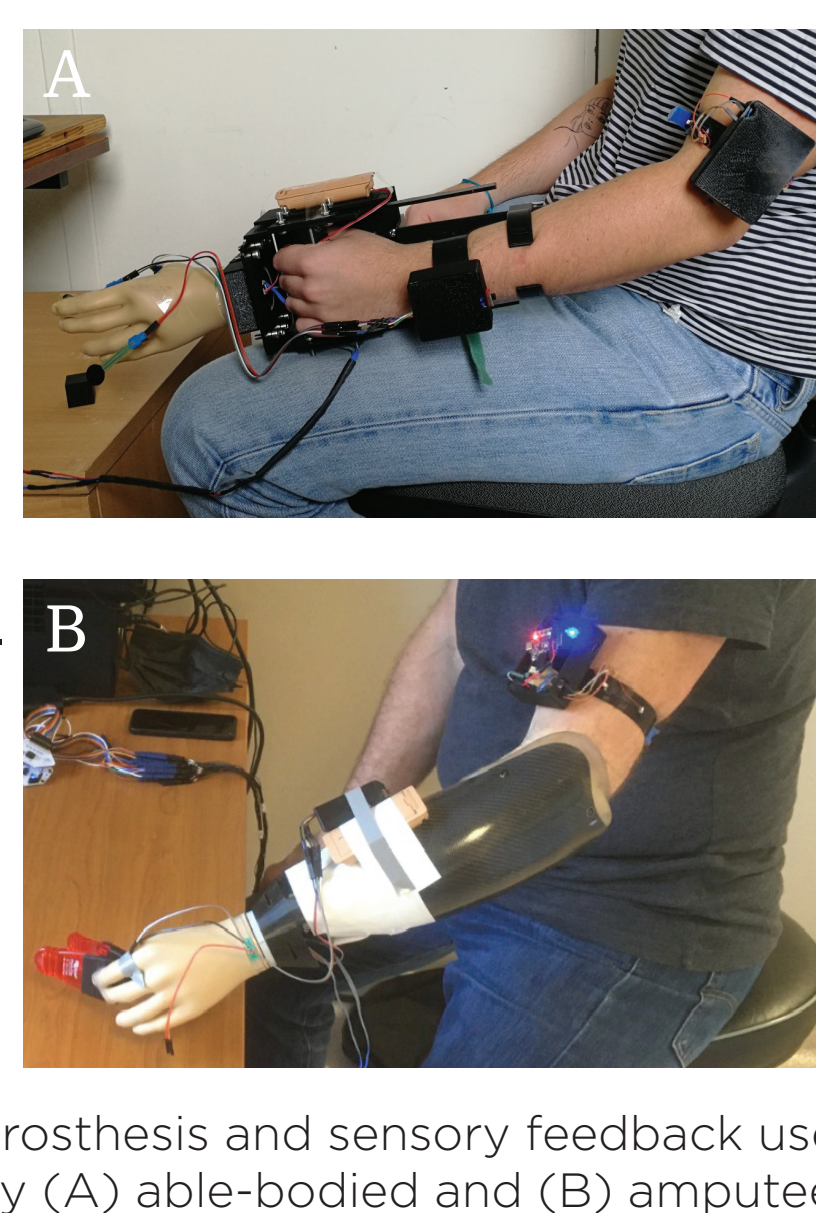
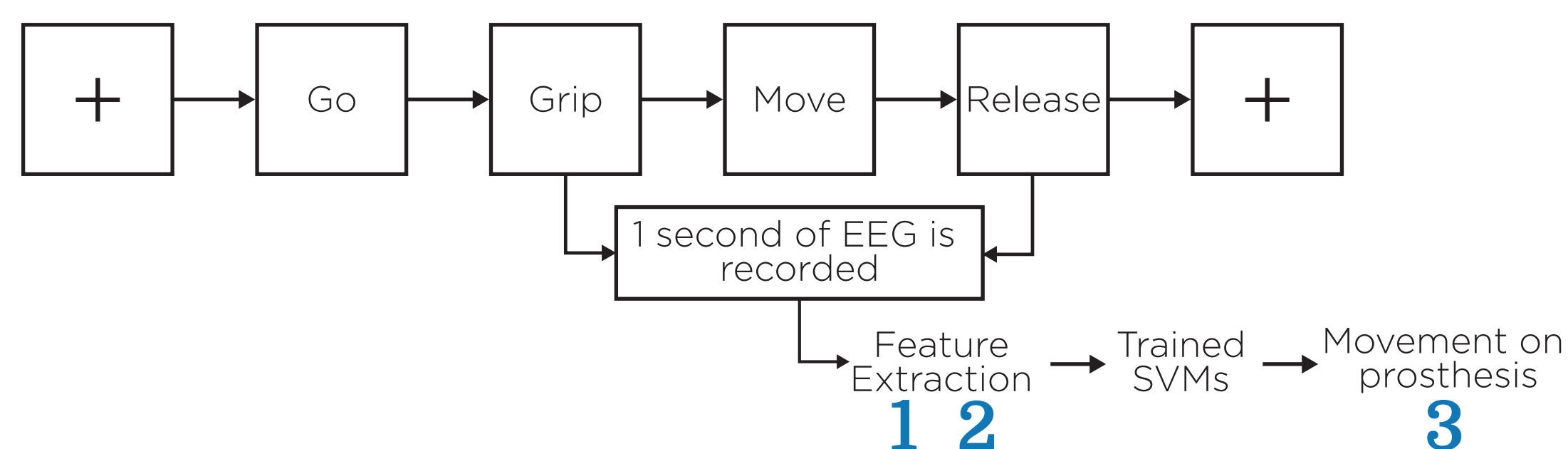
- The implementation of a finite-state machine design on the control of the prosthesis led to an increase in the classification performance on both the able-bodied and the amputee while simplifying the decision-making process after the classification.
- In real-time control, able-bodied subjects obtained higher performance compared to the one amputee, it could be due to the difference in EEG systems used with the groups (64 ActiCHamp vs. 16 electrodes OpenBCI).
- The sensory feedback system did not improve the classification performance in able-bodied and for the amputee.

Background

- The goal of developing a Brain-Machine Interface (BMI) control system for medical prosthetics is to provide robust, comfortable and easy-to-use devices for the concerned user. They need to be fast and have high performance in estimating the user's intention in real-time.
- Yet, the transition from offline to online settings often proves to be challenging (Deo et al., 2023), with a drop in performance when testing the BMI system in the latter.
- In the literature, there are numerous examples of methods and techniques aimed at targeting this issue, here applied to the control of a prosthetic hand.

Methods

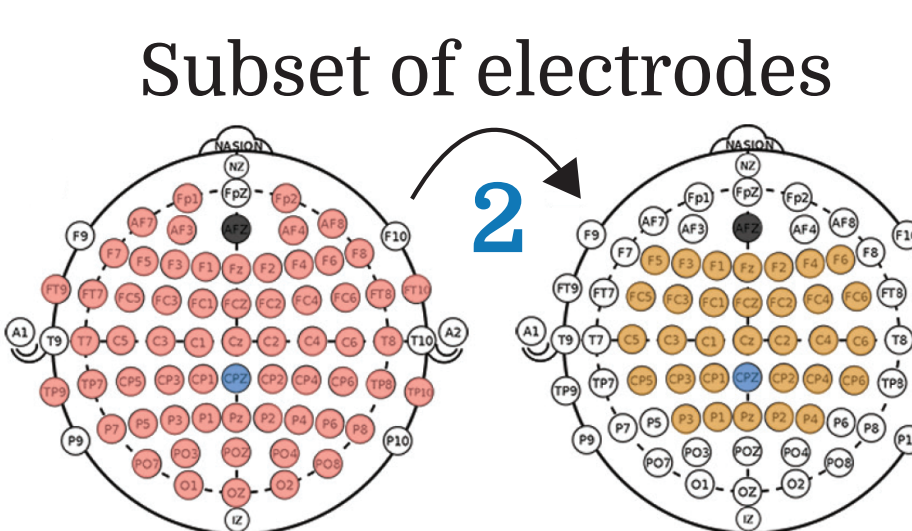
- Real-time control has been performed with amputees and able-bodied subjects during two sessions without and with the use of a sensory feedback device provided by a vibrating bracelet.
- The experiments consisted in doing a sequence of Grasping-Moving-Releasing three objects, using a modified Myobock[®] prosthesis controlled by EEG data.
- The effect of three different methods of feature extraction and decision-making process was tested on the online control performance and compared to the offline.



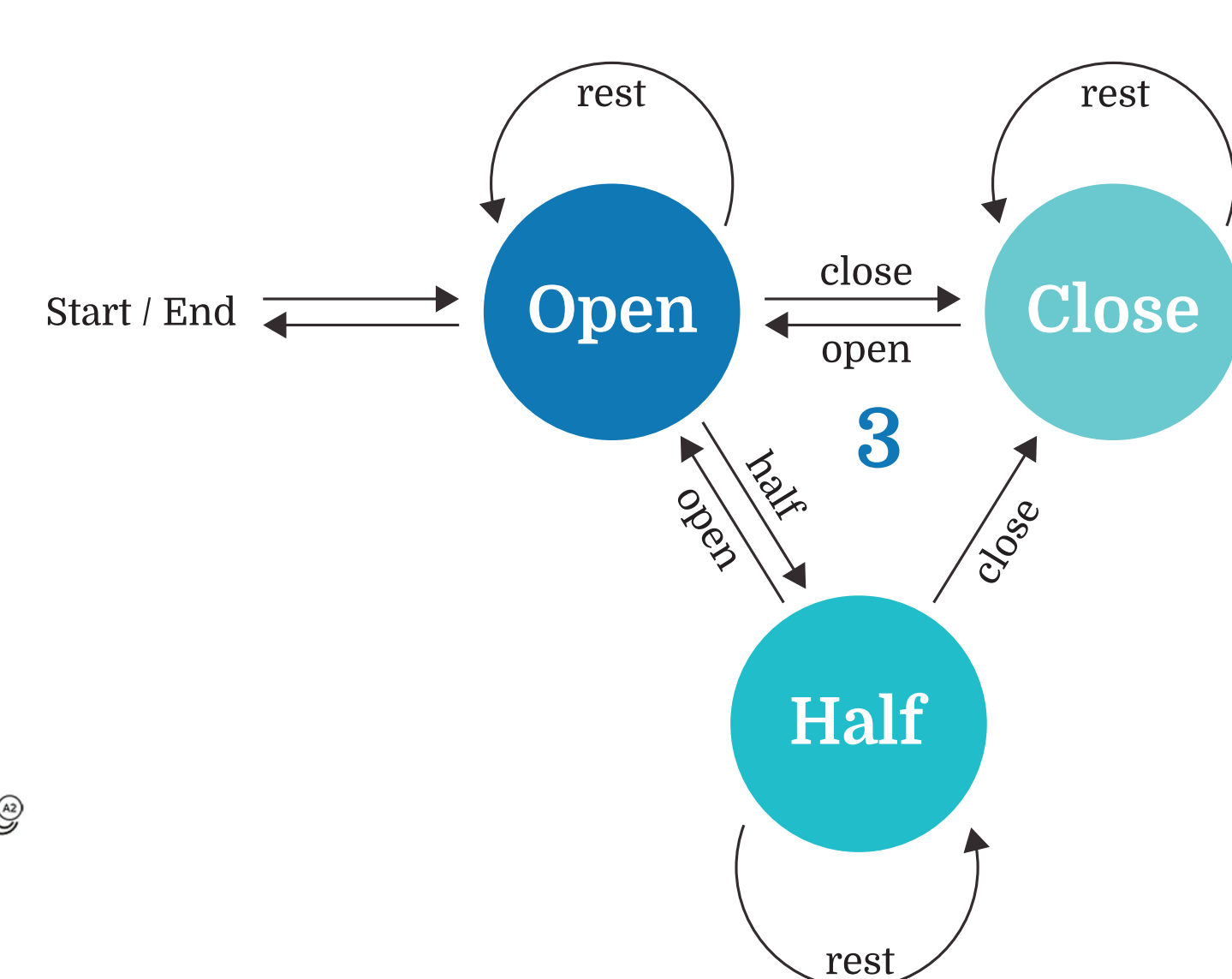
Alignment of covariance matrices 1

$$\bar{C}_{i,rest} = \begin{cases} \bar{C}_{i,train} & i = 1 \\ C_{i,1} & \text{for } i = 2 \\ \gamma(C_{i,1,rest}, C_{i,1}) & i \geq 3 \end{cases}$$

with $\gamma(C_{i,1,rest}, C_{i,1}) = \bar{C}_{i,1}^{1/2} \times (C_{i,1} \times \bar{C}_{i,1}^{-1/2})^T \times \bar{C}_{i,1}^{1/2}$



Finite-state machine



The use of the finite-state machine design can improve the performances during the grip and release phases for the two groups

While the best performances were obtained with finite-state machine for the BB (Box&Blocks) & CS (Clothespin) objects, results are more nuanced with the CUP.

Participants were performing better during the release phase compared to the grip phase

The Riemannian feature extraction pipeline, the alignment method and the selection of a subset of electrodes all increased this difference for able-bodied while only the Riemannian pipeline did for the amputee.

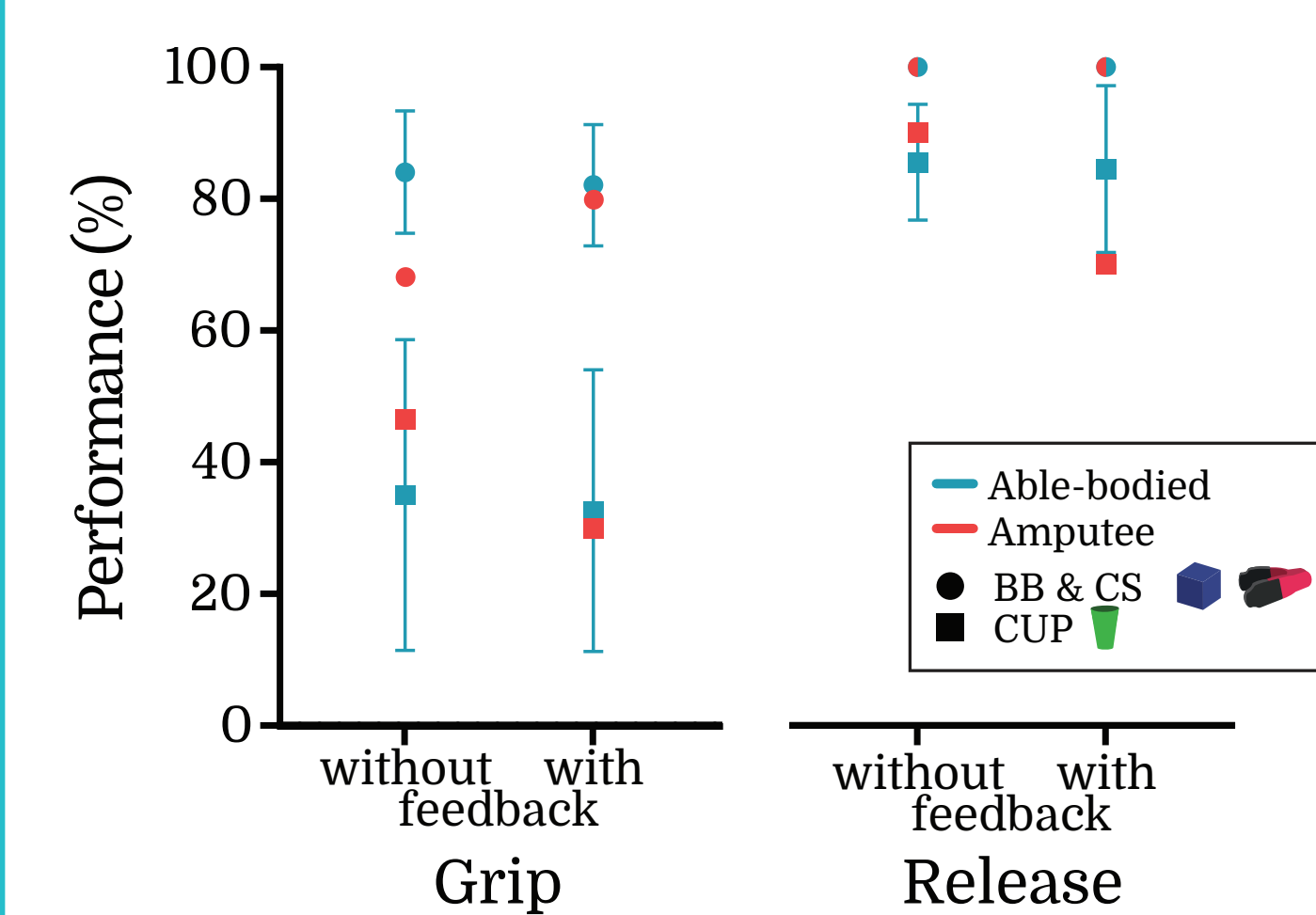
A finite-state machine design leads to a simplification of the decision process

The simplification does not prevent the system to raise errors during classification, as reflected by the low performance obtained when using the CUP object in the grip phase.

Able-bodied are performing better than the amputee

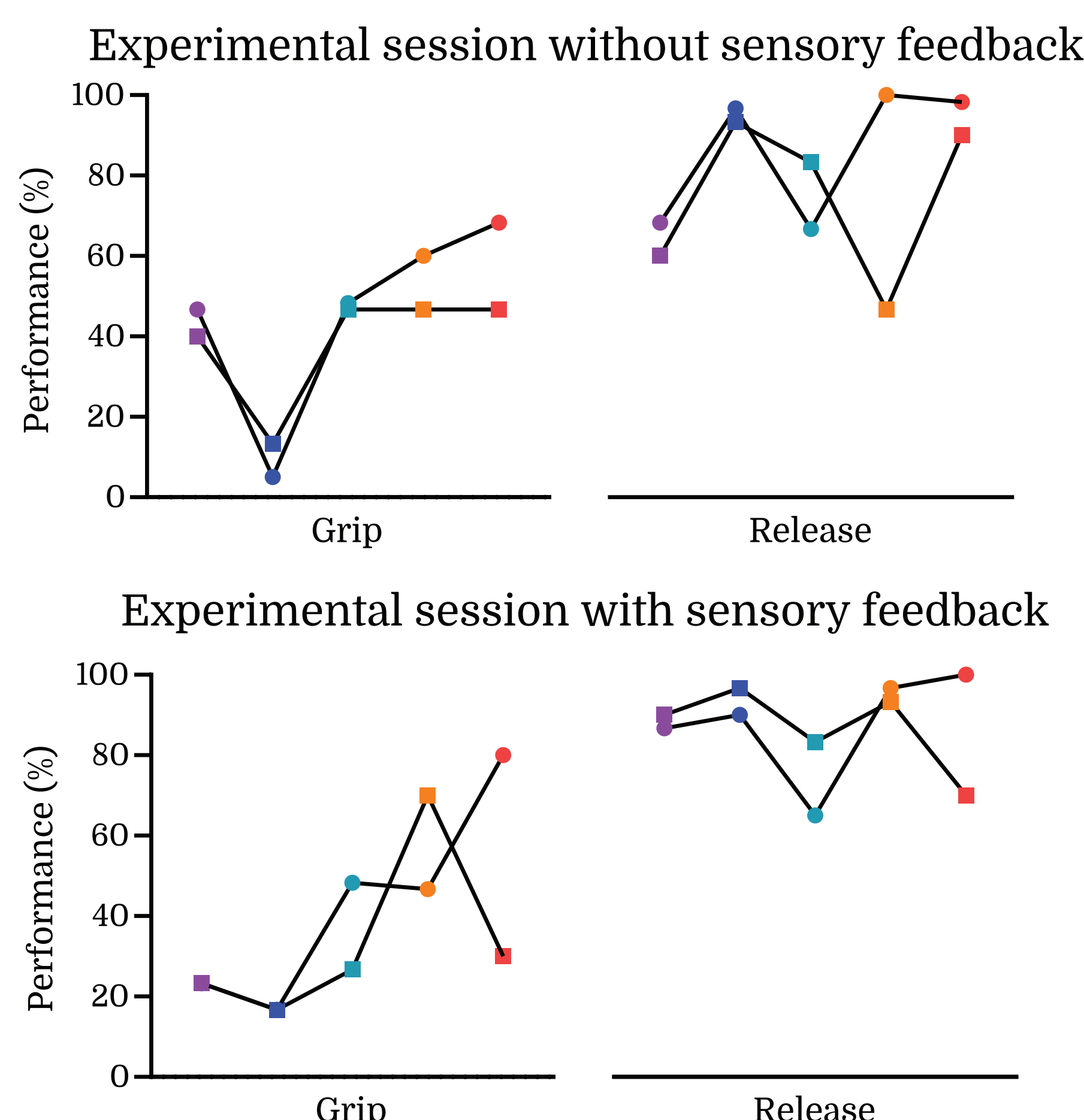
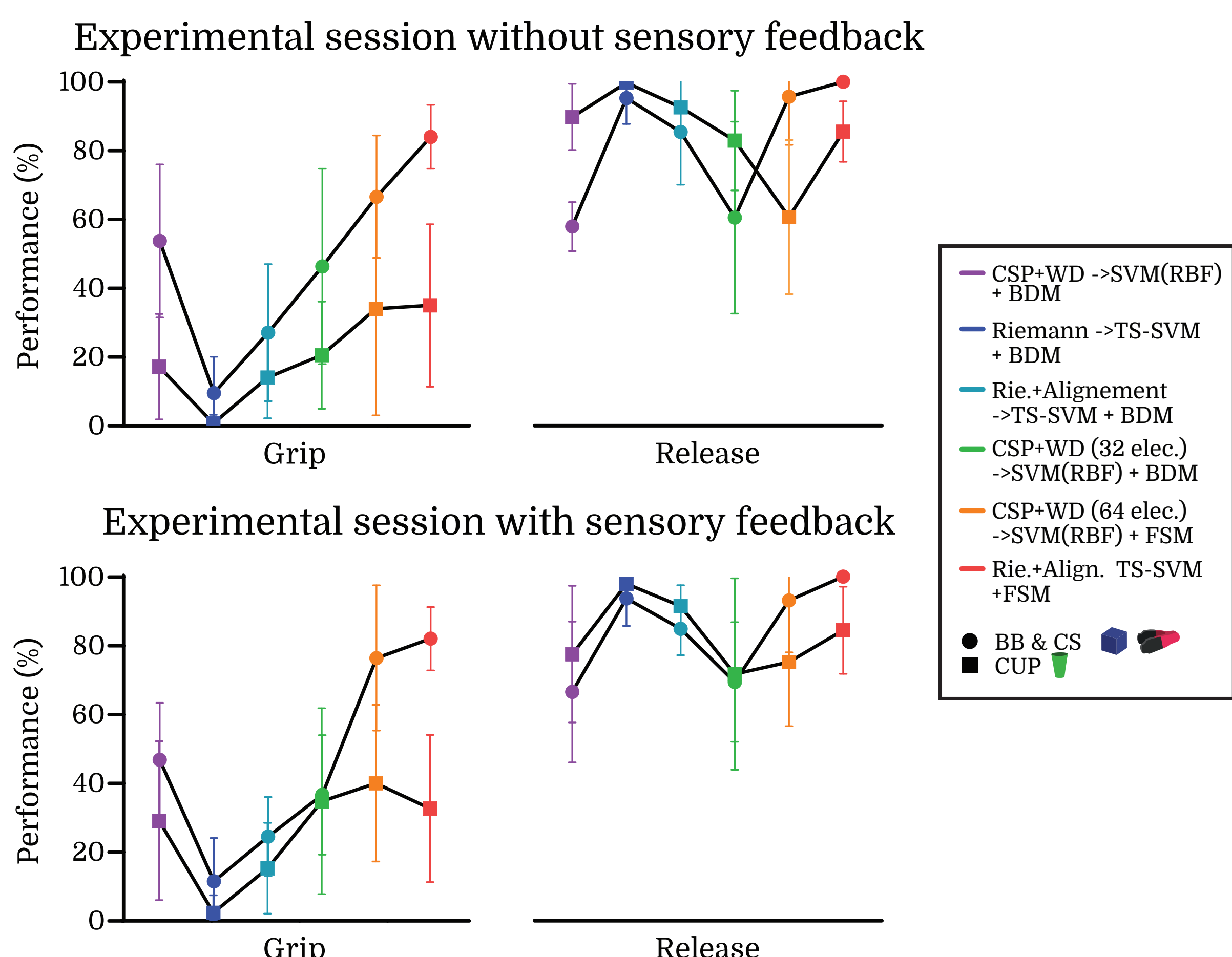
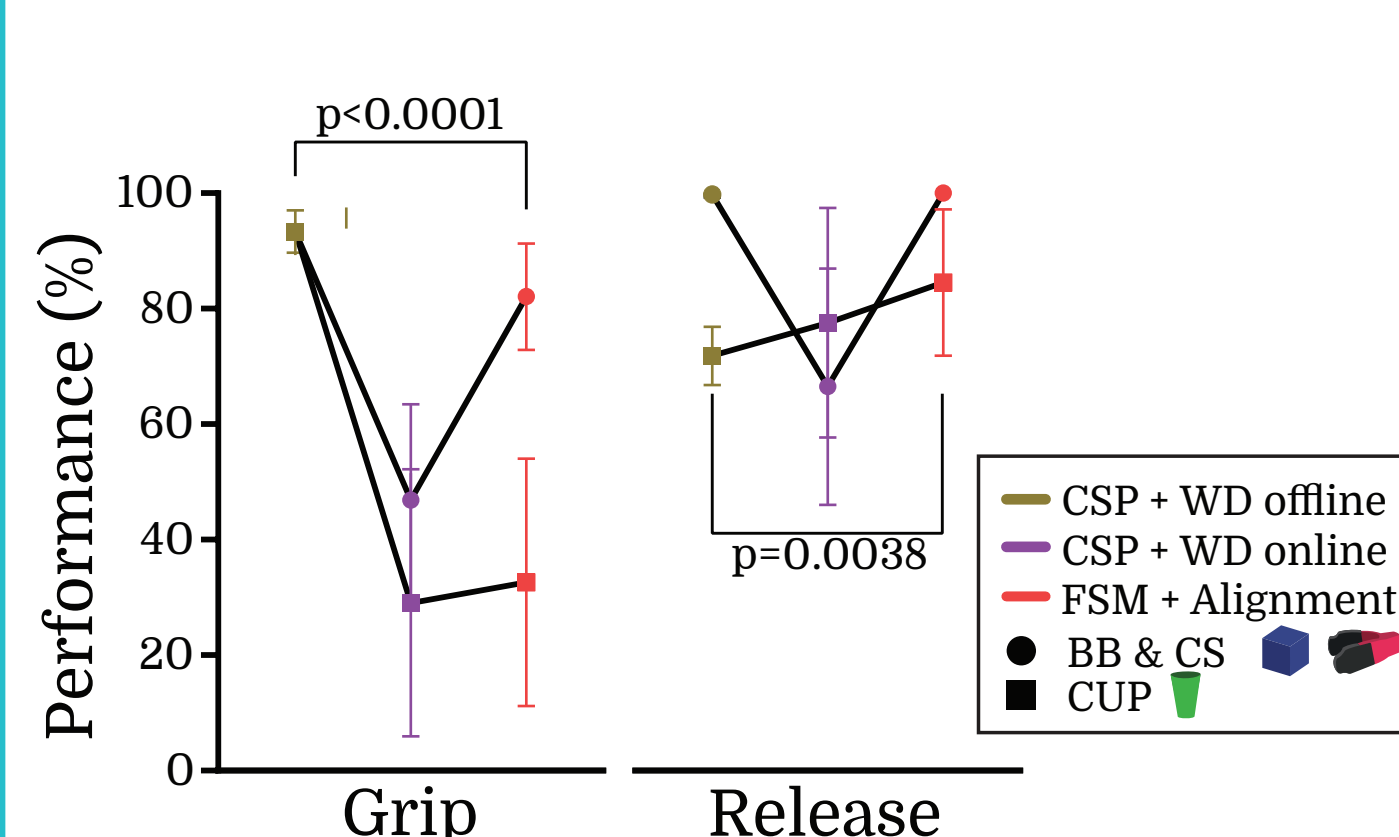
The difference could be explained by the different EEG system used for each group.

More sessions are needed to see an effect of sensory feedback



Online performances are getting closer to offline ones

With an exception for the CUP object, especially for the grip phase.



Classification performances for able-bodied (n = 19, left) and amputee (n = 1, right) using different feature extraction and decision-making methods where CSP = Common Spatial Pattern; WD = Wavelet Decomposition; BDM = Binary Decision-Making; SVM = Support Vector Machine; RBF = Radial Basis Function; TS = Tangent Space; FSM = Finite State Machine. Error bars represent average and standard deviation calculated on all of the subjects.

Conclusion

- Online classification performances were obtained with 19 able-bodied and 1 amputee subject who controlled the modified Myobock prosthesis by using the EEG data recorded in real-time and compared to the performances obtained offline.
- The effect of two different feature extraction methods and of a new decision-making process on the classification performances were studied for the same classification algorithm (SVM RBF and TS-SVM).
- The decoding of object release is always better than the object grip with both able-bodied and amputee subjects for all different combinations.

- Using a Feature Extraction method based on Riemannian Geometry and alignment of covariance matrices, and a Finite-State Machine design as decision-making process in online allows to reach classification performances obtained in offline except for the CUP object.

Acknowledgments

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To access my PhD thesis on the control of prosthetic hands using non-invasive BMIs Scan the QR code :

