Towards Brain-Robot Shared Autonomy for Independent Feeding

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From communication to activities of daily living

- BCIs have transformed communication for people with paralysis

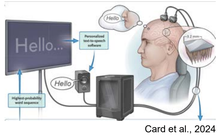
2D Cursor Control

Pandarinath et al., 2018

Handwriting

Willett et al., 2021

Speech



Card et al., 2024

Finger Movements

Willsey et al., 2025

Shah et al., 2024

- Regaining arm and hand function ranked as the #1 priority for quality of life in a survey of 681 tetraplegic individuals (Anderson, 2004)
- Reach-and-grasp with robotic arm has been demonstrated in research settings but not yet translated to ADLs like eating independently

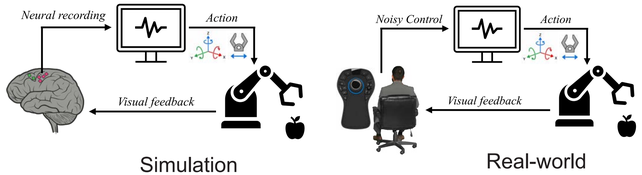
Robotic Arm Control

Hochberg et al., 2012

Neuralink, 2025

Feeding tasks for evaluating Brain-Robot Interface

- In this poster we display closed-loop results using a noisy space-mouse controller that mimics BCI user's raw decoded commands.



Simulation

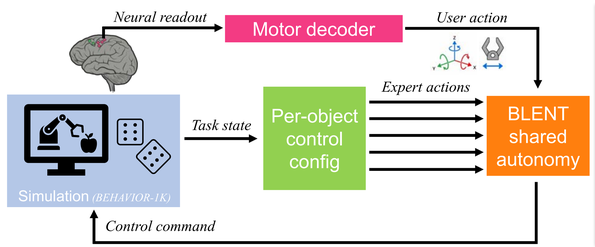
Li et al., 2024

Real-world

Reach-and-grasp

Tool-use

Shared Autonomy improves reach-and-grasp performance in simulated environment

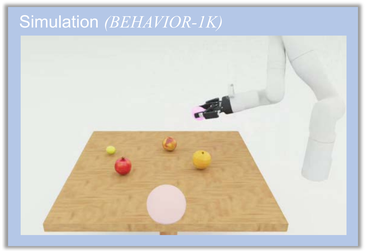


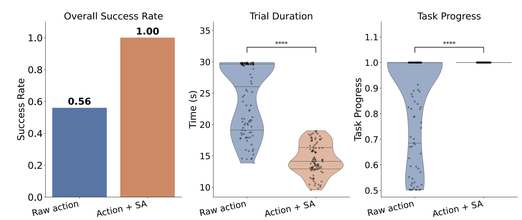
BLENT shared autonomy

Algorithm 1 BLENT Shared Autonomy

Input: task state s, user action $\mathbf{u}_{\text{in}}$, optional user prior p
State: beliefs $\boldsymbol{b}$, history buffer H (size k), cached expert actions A
Parameters: fixed assist weight $\alpha \in [0,1]$, intent coefficient β, belief decay λ

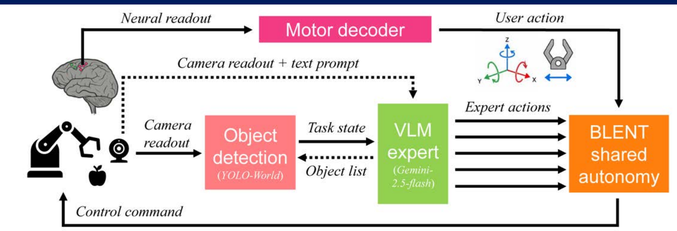
$\mathbf{u} \leftarrow \mathbf{u}_{\text{in}}$; $A \leftarrow$ ExpertActions(s)
if p is available **then** — *Obtain expert actions*
  $b_i \leftarrow b_i p_i$ if $i \in \boldsymbol{b}$ else p_i, $\forall i \in p$
  $\boldsymbol{b} \leftarrow \boldsymbol{b} / \sum_j b_j$
end if
$H \leftarrow [H_2, \ldots, H_k, \mathbf{u}]$
$\bar{\mathbf{u}} \leftarrow \text{Normalize}\left(\frac{1}{k}\sum_{j=1}^{k} H_j\right)$ — *Update belief*
for each $i \in \text{keys}(A)$ **do**
  $\boldsymbol{a}_i \leftarrow \text{Normalize}(A[i])$
  $\mathcal{L}_i \leftarrow \exp(\beta\, \boldsymbol{a}_i^{\top} \bar{\mathbf{u}})$
  $b_i \leftarrow \mathcal{L}_i$ if new; λb_i if stale; otherwise $b_i \mathcal{L}_i$
end for $\boldsymbol{b} \leftarrow \boldsymbol{b} / \sum_j b_j$
$\mathbf{a}_{\text{assist}} \leftarrow \sum_{i \in \delta} \frac{b_i}{|A[i]|} A[i]$
return $(1-\alpha)\mathbf{u} + \alpha \mathbf{a}_{\text{assist}}$ — *Blend with user action*

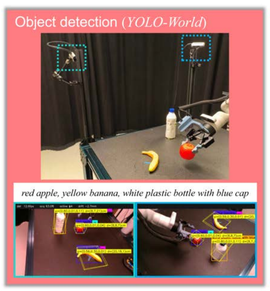


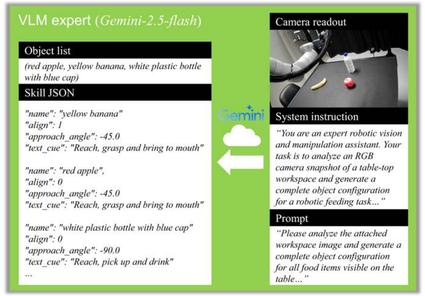


2x improvement

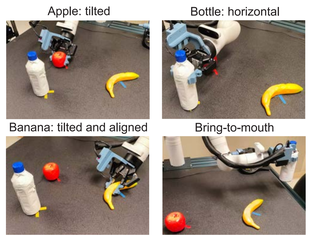
Generalization to novel objects using Vision-Language Model

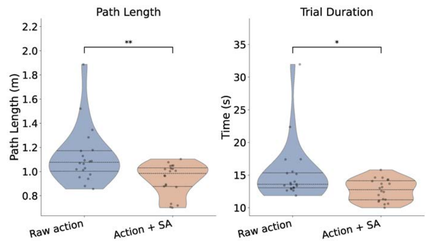






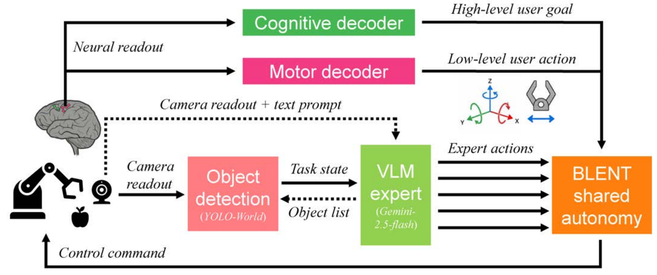
VLM identifies control profile for diverse objects in the environment

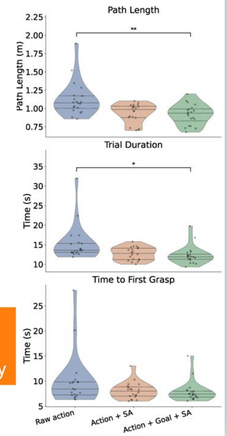




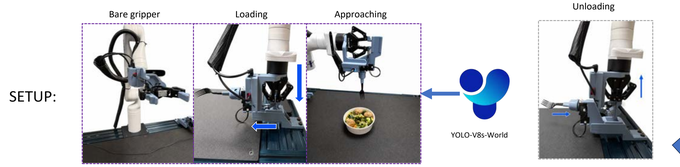
Simulated high-level decoding improves reach-and-grasp performance

- Simulate high-level user goal decoded from neural recordings
- Shared Autonomy extended to incorporate user goal
- Reduces trial duration and path length?
- Proof-of-concept for using cognitive signals in future motor BCIs





Specialized fork end-effector enables feeding for diverse dishes



Food	End Effector	Meta-skill list (recipe)
Whole apple	Gripper	Grasp
Meatball	Fork	Stab
Soup	Spoon	Stab -> Scoop
Noodle	Fork	Stab -> Twirl -> Scoop

Summary and future directions

- Shared autonomy improves reach-and-grasp performance in simulation and real-world.
- Foundation model enables generalization of feeding skills to novel objects.
- Simulated high-level decoding benefits reach-and-grasp performance.

Future directions include:

- Develop and evaluate generalized tool-use with simulated neural data.
- Deploy and evaluate the system with participants.

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References. 1. Pandarinath et al., eLife, 2018; 2. Willett et al, Nature, 2021; 3. Card et al., NEJM, 2024; 4. Hochberg et al., Nature 2012; 5. Willsey et al., Nature Med. 2025; 6. Shah et al., bioRxiv, 2024; 7. Li et al., arXiv, 2024; 8. Jenamani et al, arXiv, 2025