Coupling Sound to Movement -
Design and Assessment of Learned Auditory-Proprioceptive Integration

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Introduction

- Effect of **music** and **sound** on **bodily movement**
- Recent **technological advances** -

Human Computer Interaction (HCI)

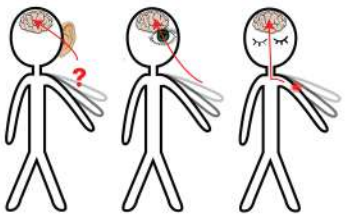
cognitive science ↔ HCI

- We design a system in order to examine a cognitive question
- Possible implications for **sonic motor rehabilitation**

- **Proprioception**
  knowledge of relative positions and movement of body parts
- **Sensory integration**

natural { - Somatic proprioception
- Visual proprioception
Alien hand illusion [Nielsen 1960, Sørensen 2005]

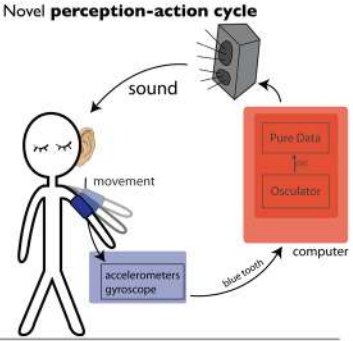
- Auditory proprioception?



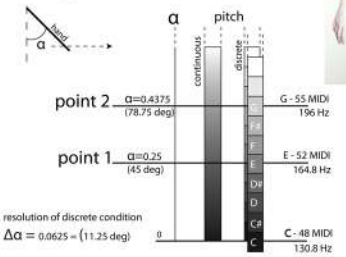
learned { - Sensory substitution [Bach-y-Rita 2003]
fast, efficient, brain plasticity
- Sound - Action association [Mutchler 2007]
hand movement - piano melodies

Methods

- Closing the sonic feedback loop
- Novel **perception-action cycle**



- **Mapping** -
  Angle of arm elevation dynamically translated to auditory pitch



- Two sonification paradigms -
  continuous ('glissando') discrete ('chromatic')

Experiment Design

- **Goal** - assess the effect of sound coupling on movement
- **Hypotheses** -
  H1. sonic feedback improves accuracy
  H2. manipulation of mapping affects movement accordingly

LEARNING → PHASE 1 → PHASE 2

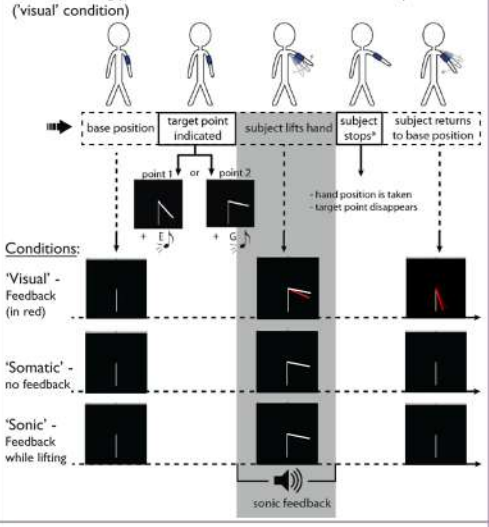
The sensory-motor contingencies

Constant mapping
H1: sonic + somatic > somatic accuracy

Manipulating mapping
H2: movement shifts accordingly

- **Motor Task** -

- Reaching with a straight arm to a target location indicated both visually and auditorily
- While lifting, sonic feedback to movement is presented ('sonic' condition) or not ('somatic' condition)
- In the learning phase visual feedback to hand movement is presented ('visual' condition)



- **Experimental procedure**

LEARNING — 15 minutes of mixed 'visual', 'somatic' 'sonic' and 'visual'+'sonic' conditions

PHASE 1 — Constant mapping

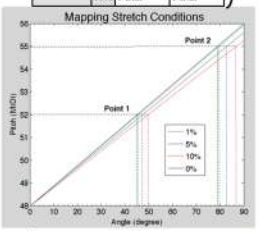
	Point 1	Point 2
Somatic	3 trials	3 trials
Sonic	3 trials	3 trials

PHASE 2 — Manipulating mapping

		Point 1	Point 2
Somatic		3 trials	3 trials
Sonic	1%	1 trial	1 trial
	5%	1 trial	1 trial
	10%	1 trial	1 trial

×3

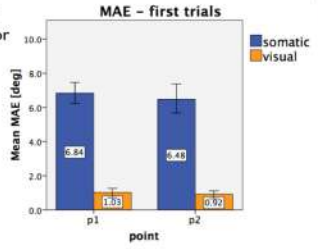
- Repeated measures
- Randomized



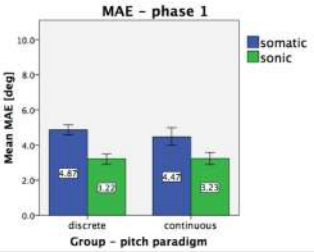
- Two independent groups:
  - Continuous pitch
  12 participants
  - Discretized pitch
  12 participants
- Participants were not informed about mapping manipulation
- Asked whether noticed at the end

Results

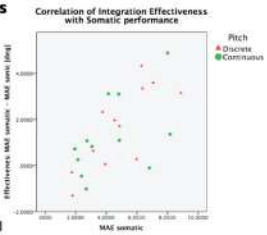
- Accuracy measure: Mean Absolute Error (per subject)



- H1 significant in both groups
  Discrete: p = 0.015
  Continuous: p = 0.023
  (Wilcoxon signed rank test, 2-tailed)

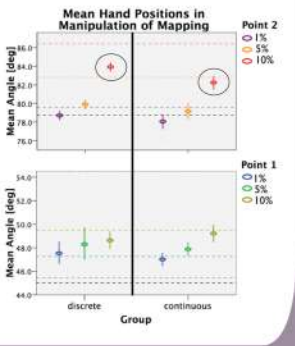


- **inverse effectiveness** of sensory integration
  The worse the performance in the individual modality (bigger somatic MAE), the more it improves from the integration (higher effectiveness = somatic - sonic MAE)



Spearman's rho = 0.69, p<<0.01

- **Phase 2** - Mapping manipulations



- H2 significant
  Mixed ANOVA:
  main effect of manipulation: highly significant (p<< 0.01) across group for both points

Conclusions

- Quantitative assessment of **learned sensory integration**
- Effective, fast utilization of sonic feedback by the motor system
- Manipulation of learned mapping - possible **technique for motor neuro-rehabilitation reinforced with sound**

Future Work

- Assess dependence on hearing abilities
  Try on musically trained subjects
- Predict individual responses from hearing abilities and somatic permormance
- Analyze threshold for awareness to mapping manipulation and the relation between the effect and awareness to it
- Apply for patients with motor disabilities