TRAINING STIFFNESS PERCEPTION: KNOWLEDGE OF RESULTS AND MODALITY EFFECTS

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Abstract

Stiffness perception demands integration of both the haptic and the visual modalities. Recent studies argued for a facilitatory effect of multisensory training on unisensory learning, thus suggesting that visual-haptic training will enhance haptic-only performance. An additional training manipulation, which is also argued as having an enhancing effect, is Knowledge of Results (KR). In this study we examined whether practice alone improves stiffness perception and how the addition of KR and/or visual information during training affects learning in unisensory haptic discrimination. The results showed that practice induced gradual improvement in unimodal stiffness discrimination ability. Affordance of visual information during training did not induce better uni-sesnsory learning, but only transiently enhanced performance during the training itself. We didn't find evidence that training with KR enhances accuracy. However, we found temporary effects of KR and visual-haptic trainings on decision times: while visual-haptic training resulted in slower decisions, KR training induced faster decisions.

Stiffness sensitivity is crucial for perception and discrimination of objects and is essential for many complex tasks (Lederman & Klatzky, 2009), including medical procedures such as surgery and teleoperation (Howell et al., 2008; Sherman, Cavusoglu & Tendick, 2000).

During the examination of an object, the haptic system acquires tactile information as well as information about arm displacement in conjunction with signals of applied force (i.e. kinesthesis information) (Clark & Horch, 1986). Yet information regarding the displacement or deformation of an object may also be obtained from the visual system (Lederman & Klatzky, 2009). However, in many surgeries procedures for example, the visual field is typically occluded (as in Maxillo-Facial Surgeries), thus the surgeon has to rely solely on the information obtained from the haptic system.

Perceptual learning has been most extensively studied in the visual and auditory domains (Goldstone, 1998).Recent visual and auditory studies showed that multisensory stimuli presentation during training facilitate unisensory learning (Seitz, Kim & Shams 2006; Shams & Seitz, 2008; Lehmann & Murray, 2005). This suggests that unimodal haptic learning may also benefit from bimodal visual-haptic training . This possibility was not systematically addressed in the domain of tactile perception.

An additional training manipulation, which is often argued for enhancing performance, is Knowledge of Results (KR) (Adams, 1987). Yet, as indicated by Salmoni, Schmidt & Walter (1984), most of the KR experiments failed to separate the temporary effects of KR manipulations from long-term effects (learning). Their results showed that when KR was withdrawn, performance deteriorated.

Although its importance, training of stiffness perception has not been addressed systematically. In continuation to our previous study that addressed the effects of order and sensory modality in a single session training (Korman et al., 2011), in the current study we investigated the course of learning in uni-modal stiffness perception and how it is affected by different sensory conditions (uni-haptic or visual-haptic),as well as by affordance of information feedback during training.

Method

Setup

The apparatus included a computer, monitor, 3D eyeglasses, mouse, and the PHANToM Desktop[1] - a pen-like stylus arm gripped and moved as in handwriting (see Fig. 1).

Figure 1. Experimental set-up. The computer screen with two targets, Phantom, 3D glasses and a mouse.

Task and experimental design

The experimental task was a Two Alternative Forced Choice (2AFC) discrimination task (Gescheider, 1997). On each trial two targets were presented on the screen as two red squared plates. Across all conditions, participants had to probe the targets with the stylus and determine **which target is softer.** Each discrimination pair was comprised of one standard stiffness value of constant 0.25 N/mm, and one comparison value out of the 11 possible. The values were chosen in a preliminary pilot study (not reported here), to ensure that discrimination is possible in this range, though not too easy, in order to address possible improvements.

Two types of sensory stimuli were used in the study: **Haptic (H)** - during target probing, only the haptic property of stiffness was presented (with fixed, non-matched visual component – target square did not change its size and the stylus disappeared after contact with the target square to exclude visual feedback from stylus movement). **Visual-Haptic (VH)** - during target probing, matched haptic and visual changes (congruent in terms of visual target size and force-feedback) appeared for each of the targets under the application of force.

A total of 48 Technion students participated in the study. The experimental procedure included training on the discrimination task for two sessions in two consecutive days. All subjects performed three blocks of the task in each day (test-training-test, see Fig. 2), separated by 5 min rest. Each block included 11 paired comparisons with the standard stiffness value; for each comparison, 10 repetitions were preformed, altogether 110 trials per block. Experimental session lasted approximately one hour in each day.

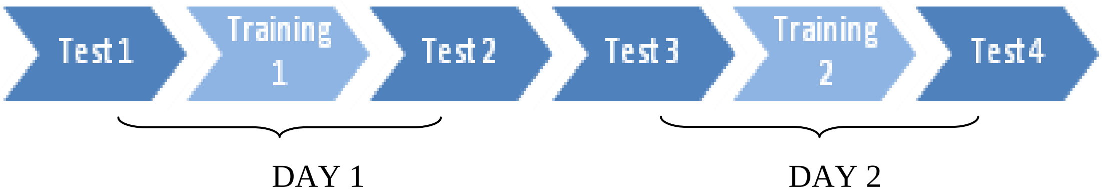

Figure 2. The time-course of training and re-tests

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[1] Full technical descriptions of this virtual haptic system are available at http://www.reachin.se and http://www.sensable.com.

At training two variables were manipulated between participants: KR and/or addition of congruent visual information during the training blocks. 2X2 design was adopted: Four groups, differing only in the training conditions were re-tested on uni-haptic performance before and after the training blocks on each training day (Table 1).

	KR	**NoKR**
H	H-KR (12 subjects)	H-nKR (12 subjects)
VH	VH-KR (12 subjects)	VH-nKR (12 subjects)

Table 1. The experimental groups.

Results

Proportion of Correct answers (PC)

We conducted repeated measures GLM analysis with 11x6x2x2 design (comparison's difficulty, block, KR, VH). Analysis of baseline performance in all experimental groups did not reveal significant differences. As expected, significant difficulty effects were found: Participants in all groups exhibited higher PC for easier comparisons (difficulty effect: F(10,440)=315.11, p<0.001). The results showed significant and persistent improvement in unimodal stiffness discrimination ability from the first to the last test block, induced by two-day practice, in all groups (practice effect: F(5,220)=24.35, p<0.001, see Fig. 3 for comparison of normalized gains attained by different groups).

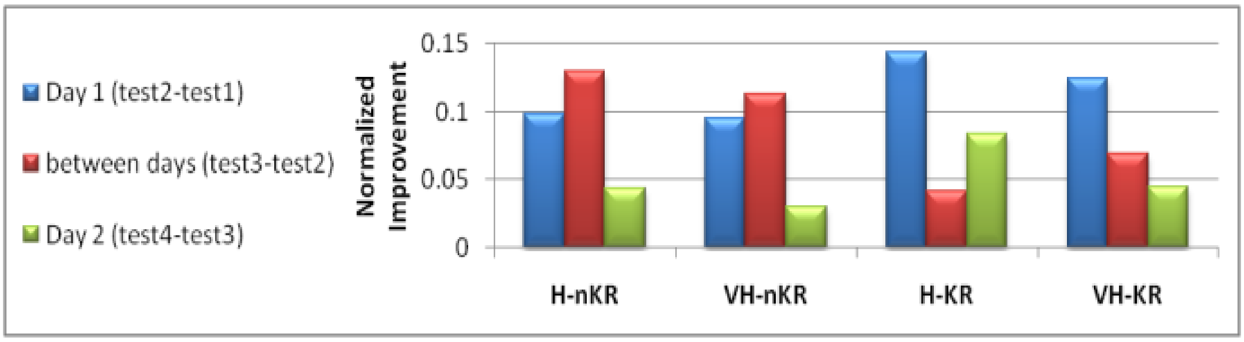

Figure 3. Normalized Improvements in PC at day 1 (blue), day 2 (green) and between the days (red)

Stiffness discrimination learning was evident in within and between session gains with significant off-line, consolidation gains found in all groups (indicated by the red bars in Fig.3, (F(1,44)=12.3 p=0.001). However, the type of training affected the relative amount of gains: consolidation gains were smaller in the KR groups , possibly due to the relatively larger within-session improvement observed during the first day in these groups (the blue bars). Addition of visual information resulted in higher PC scores during training blocks, but lower PC scores for haptic-only test blocks. In addition, significant interaction between block, difficulty level and VH training was found (block*VH: F(5,220)=2.63, p=0.024;

Block*VH*Difficulty: F(50,2200)=1.39, p=0.038), see Fig. 4. Altogether, these findings show that multisensory training does not necessarily facilitate later unimodal performance, as was suggested for the combination of visual and auditory modalities.

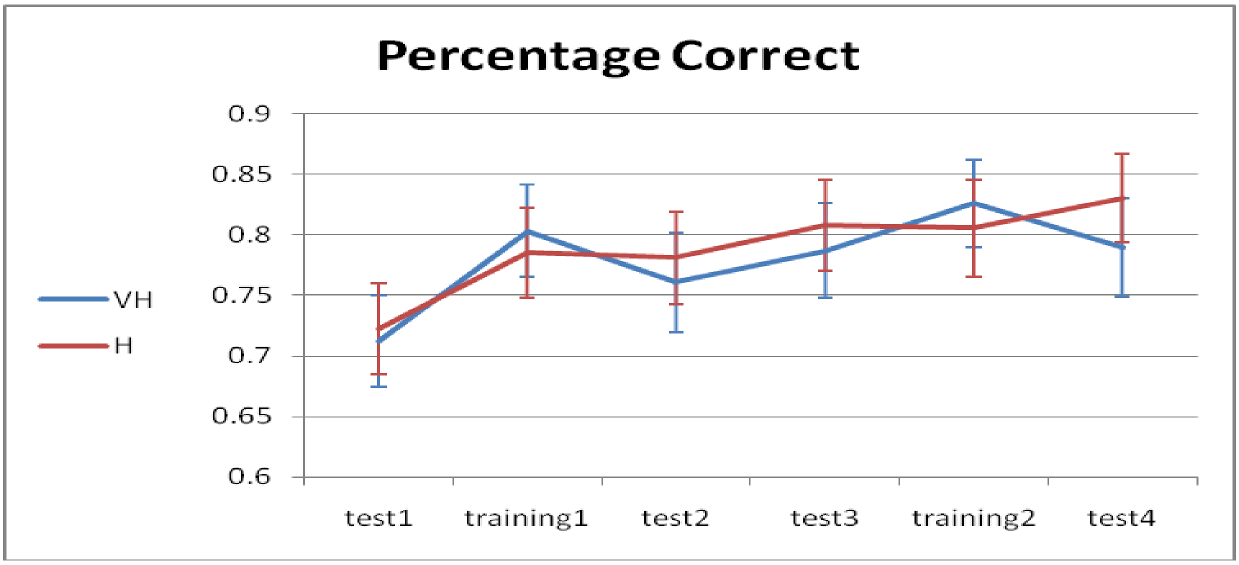

Figure 4. VH (blue) vs H (red) training in terms of absolute improvements in PC.

Decision Time (DT)

Temporary effects of KR and VH trainings on decision time were found: while VH training resulted in slower responses (Fig. 4), KR training induced faster responses, as compared with the control group (Fig.5). When present together VH and KR cancel each other. Nevertheless, as noted, these effects disappeared in the long run and were mainly evident during the training blocks (Significant interactions- Difficulty*Block: F(50,2200)=1.59, p=0.005; Difficulty*Block*VH: F(50,2200)=1.43, p=0.026); Difficulty*Block*KR: F(50,2200)=1.7, p=0.001). In addition, DT analysis revealed negative consolidation effect (F(1,44)=15.8, p<0.001), suggesting that off-line improvement in accuracy of discrimination between the last block on the first day to the first block on the second day is accompanied by slowering down of decision time.

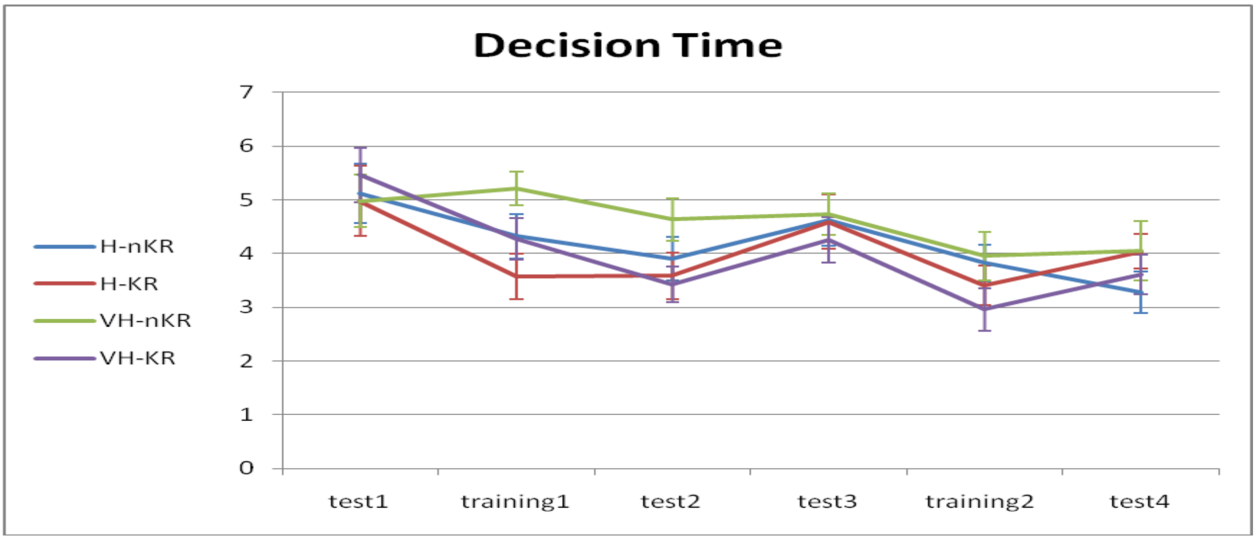

Figure 4. VH (red) vs. V (blue) training in terms of absolute improvements in Decision Time (sec). Block correspondence as in Fig. 3

Conclusions

Our study addressed the time course of learning a stiffness discrimination task. The results showed that practice alone induced significant and persisting gains in stiffness discrimination ability at all difficulty levels. Mixed consolidation effects (off-line learning) were found: accuracy was improved, but slowing down of decision time was observed between days of training. Training with KR resulted in faster decisions; in contrast, the addition of visual information induced in slower decisions. However, both effects disappeared in the long run. Most importantly, visual-haptic training resulted in better stiffness discrimination during the training itself, but this enhancement did not generalize to the haptic only post-training re-tests. These findings in the visual-haptic domain suggest that multisensory training does not necessarily facilitate later unimodal performance, as was suggested for the combination of visual and auditory modalities (Shams & Seitz, 2008). Information feedback has impact on the fast, within-session learning, but not on the consequences of the multi-session training.

To our knowledge, this is the first study that specifically addressed the time-course of stiffness discrimination learning and evaluated effects of training with additional modal or information feedback. Our findings have implications for optimization of training protocols in virtual environments for perceptual motor tasks relying on stiffness perception, such as surgery.

Acknowledgments

This work was supported by the SKILLS Integrated Project (IST-FP6 #035005, http://www.skills-ip.eu) funded by the European Commission.

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