Psychological Science OnlineFirst, published on November 21, 2016 as doi:10.1177/0956797616678189

Research Article

Psychological Science
1–8

DOI: 10.1177/0956797616678189
pss.sagepub.com

Action Experience Drives Visual-Processing Biases Near the Hands

Laura E. Thomas
Center for Visual and Cognitive Neuroscience, Department of Psychology, North Dakota State University

Abstract
Observers experience affordance-specific biases in visual processing for objects within the hands' grasping space, but the mechanism that tunes visual cognition to facilitate action remains unknown. I investigated the hypothesis that altered vision near the hands is a result of experience-driven plasticity. Participants performed motion-detection and form-perception tasks—while their hands were either near the display, in atypical grasping postures, or positioned in their laps—both before and after learning novel grasp affordances. Participants showed enhanced temporal sensitivity for stimuli viewed near the backs of the hands after training to execute a power grasp using the backs of their hands (Experiment 1), but showed enhanced spatial sensitivity for stimuli viewed near the tips of their little fingers after training to use their little fingers to execute a precision grasp (Experiment 2). These results show that visual biases near the hands are plastic, facilitating processing of information relevant to learned grasp affordances.

Keywords
visual processing, plasticity, action affordances, open data

Received 7/15/16; Revision accepted 10/17/16

A decade of research has documented a variety of changes in performance on visual cognition tasks when observers view information within rather than outside of their hands' grasping space. The observed differences include alterations in perception (Cosman & Vecera, 2010), attention (e.g., Abrams, Davoli, Du, Knapp, & Paull, 2008; Reed, Grubb, & Steele, 2006), and memory (e.g., Kelly & Brockmole, 2014; Tseng & Bridgeman, 2011; for reviews, see Brockmole, Davoli, Abrams, & Witt, 2013; Tseng, Bridgeman, & Juan, 2012). Although a popular theoretical account of altered vision near the hands posits that information presented in near-hand space receives enhanced processing in the high-temporal-acuity magnocellular (M) visual pathway at the expense of the high-spatial-acuity parvocellular (P) pathway (e.g., Abrams & Weidler, 2014; Gozli, West, & Pratt, 2012; for a review, see Taylor, Gozli, Chan, Huffman, & Pratt, 2015), recent work suggests that visual biases near the hands can shift depending on both task demands (Goodhew & Clarke, 2016) and the hands' positioning (Bush & Vecera, 2014; Thomas, 2013). This flexibility in visual biases within the hands' grasping space may reflect an adaptive sensitivity to behavioral contexts. Objects within reach afford immediate interaction, and by prioritizing processing of action-relevant information, the visual system could give observers an edge in producing effective actions.

A recent study supports the idea that action affordances have an impact on visual processing (Thomas, 2015). Participants in this study performed global-motion-detection and global-form-perception tasks designed to measure temporal and spatial sensitivity, respectively, while adopting different hand postures. In some conditions, participants held their hands near the display in a power-grasp posture—creating an affordance for a fast and forceful action using the fingers as a unit (e.g., catching a ball). In other conditions, participants held their hands near the display in a manner that afforded a precision grasp—ready to use their thumb and forefinger to perform a more delicate and detail-oriented action (e.g., threading a needle). Whereas the power-grasp posture

Corresponding Author:
Laura E. Thomas, North Dakota State University, Department of Psychology, NDSU Dept. 2765, P. O. Box 6050, Fargo, ND 58108-6050
E-mail: laura.e.thomas@ndsu.edu

facilitated performance on the motion-detection task, the precision-grasp posture instead facilitated performance on the form-perception task. The actions participants were ready to perform when they viewed a stimulus led to affordance-specific alterations in visual sensitivity: A power-grasp posture biased processing in favor of temporal sensitivity to aid fast action, but a precision-grasp posture led to a bias toward spatial sensitivity to facilitate detailed-oriented action.

Although visual biases near the hands seem to be tied to an adaptation that enables more effective action production, the driving force behind these biases remains unclear. Do short-term learning experiences contribute to altered vision near the hands? Visual biases near the hands may be an adaptation specific to the hands' most common actions—the overlearned power and precision grasps that constitute the majority of observers' interactions in gripping nearby objects (Napier, 1956). However, the uses to which observers put their hands in the short term may also shape the manner in which they process information near their hands. Is the visual system informed not only by the actions people are prepared to take, but also by their recent action experiences?

The literature on peripersonal space and vision provides intriguing evidence supporting short-term, experience-induced changes in visual processing near used tools (Reed, Betz, Garza, & Roberts, 2010) and the hands of other actors (Sun & Thomas, 2013). These changes may reflect a temporary incorporation of these external objects into an observer's own body schema (e.g., Iriki, Tanaka, & Iwamura, 1996; Soliman, Ferguson, Dexheimer, & Glenberg, 2015). When observers begin to represent external objects as extensions of their own hands, this incorporation may induce a fixed set of visual-processing biases associated with the hands' most common action affordances. That is, although representations of perihand space are subject to action-driven changes, visual-processing biases associated with the space near the hands may be tied to standard power- and precision-grasp affordances. However, I hypothesized that recent experience acting with the hands may instead introduce action-specific shifts in the way people process information near their hands.

To examine this possibility, in two experiments, I asked participants to perform a global-motion-detection task and a global-form-perception task under hands-near and hands-far conditions both before and after a short training session designed to help them learn a *novel* grasp affordance. Participants learned to execute a novel power grasp using the backs of their hands (Experiment 1) or a novel precision grasp using the tips of their little fingers (Experiment 2). Performance in the hands-near and hands-far conditions did not differ before training. However, following training with the novel grasp affordances, positioning the backs of the hands near the display facilitated motion detection, whereas positioning the tips of the little fingers near the display instead enhanced form perception. The results of these experiments show that action drives visual biases in perihand space and point to the flexibility and adaptability of the visual system in weighting processing on the basis of recent experience.

Method

Overview of the visual-processing tasks

All participants performed both a global-motion-detection and a global-form-perception task. The tasks were presented with MATLAB and Psychophysics Toolbox (Brainard, 1997; Kleiner, Brainard, & Pelli, 2007; Pelli, 2007) on a 20.1-in. monitor set to a resolution of 1,024 × 768 pixels at a refresh rate of 60 Hz. The computer monitor rested on a desk face up (see Fig. 1), and participants looked down at the stimuli. For each task, participants viewed arrays of 100 one-pixel black dots presented in a 150- × 150-pixel area in the center of a white background.

In the motion-detection task, participants viewed an eight-frame motion sequence of dots randomly positioned

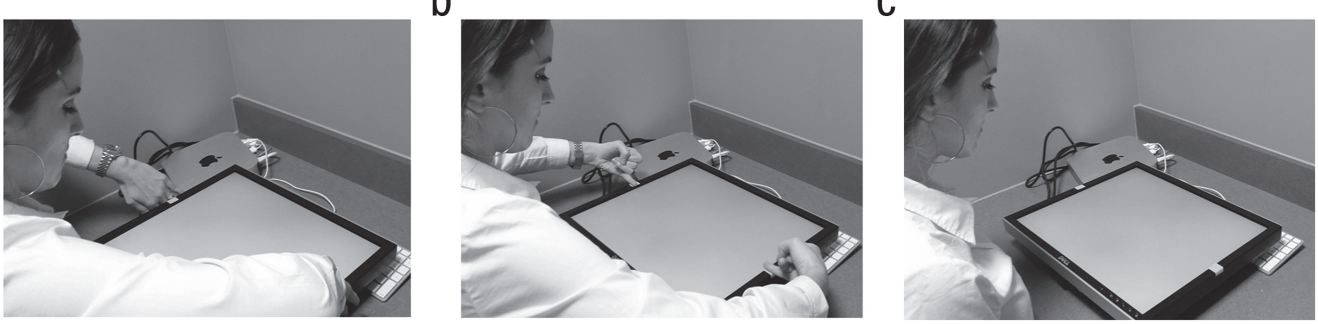

Fig. 1. Participants' position in (a) the backs-of-hands-near condition, (b) the little-fingers-near condition, and (c) the hands-far condition.

within the central area. Each frame appeared for 50 ms, for a total viewing time of 400 ms per trial. On each frame transition, a portion of the dots, the signal dots, shifted 1 pixel in the same direction. This signal direction—either left or right—was randomly determined on each trial. The remaining portion of the dots, the noise dots, also shifted 1 pixel. The direction of each noise dot's motion was randomly determined at the start of each trial. The locations of the individual dots were randomly determined every two frames in order to minimize local motion cues; this prevented participants from tracking individual dots across an entire trial. If the programmed displacement moved a dot outside of the presentation window, the dot was repositioned on the opposite side of the window for the next frame.

After participants viewed a motion sequence, they verbally indicated whether they had perceived primary global motion to the left or right. An experimenter sitting next to the participants but unable to see the display entered these responses using a keyboard. Participants' global-motion thresholds were determined using a staircase procedure. A block began with 80% signal dots. The percentage of signal dots decreased following three correct responses and increased following a single incorrect response. Initially, the percentage of signal dots changed by 8%. After three reversals, the percentage of signal dots changed by 4%, and following the fifth reversal, the percentage of signal dots increased or decreased by 2%. A block of motion-detection trials terminated after eight reversals. I determined the motion-coherence threshold for a block by calculating the mean percentage of signal dots present for the final four reversals in that block.

In the form-perception task, participants viewed a static array of dots positioned within the central presentation window for 400 ms. On each trial, pairs of dots were placed at random locations and oriented to form either a radial or a concentric Glass pattern (Glass, 1969). Whether these signal dots were arranged into a radial or concentric pattern was determined randomly across trials. The remaining dots, the noise dots, were placed at random within the presentation window. Following each presentation, participants verbally indicated whether they perceived a radial or concentric global pattern. An experimenter entered these responses with a keyboard. Form-perception thresholds were determined using the same three-down/one-up staircase procedure employed for the global-motion task.

Experiment 1

Sixty volunteers[1] from North Dakota State University's Psychology Department participant pool participated for course credit. All participants had normal or corrected-to-normal vision. They performed the global-motion-detection and global-form-perception tasks while holding their hands in two different postures: In the backs-of-hands-near condition, the backs of their hands rested against the sides of the display (see Fig. 1a), and in the hands-far condition, their hands remained in their laps (see Fig. 1c).[2] In addition to performing these visual-processing tasks, participants took part in a training session in which they repeatedly transferred a small plunger between 10 possible target locations using the backs of both hands (see Fig. 2a). Previous work had shown that tasks involving transfer of a small plunger elicit natural power-grasp actions (e.g., Rosenbaum, Halloran, & Cohen, 2006), so performing this task with the backs of the hands taught participants that they could use this atypical posture to successfully carry out a power-grasp action goal. An experimenter sat next to the participants and read from a list of randomly generated target locations. After hearing a target location, the participants secured the handle of the plunger between the backs of their hands, lifted the plunger, placed it on the target location, and then let go of the plunger. The participants then placed their hands in their lap, at which time the experimenter read the next target location. Participants spent 6 min engaged in this grasp-training task.

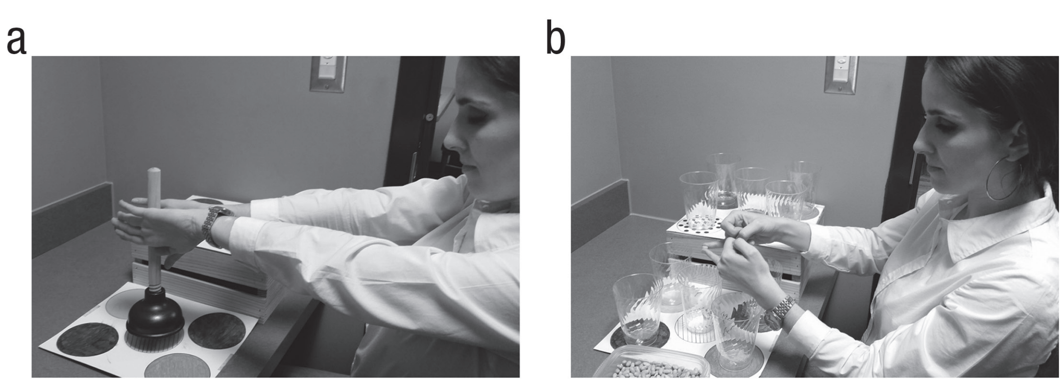

Fig. 2. Grasp training for (a) the novel power grasp (Experiment 1) and (b) the novel precision grasp (Experiment 2).

Participants performed eight blocks of the global-motion-detection task and eight blocks of the global-form-perception task before grasp training and an additional eight blocks of each of these tasks after grasp training in a counterbalanced order. They adopted the backs-of-hands-near posture for half of the blocks and the hands-far posture for the other half of the blocks. Written instructions at the beginning of each block indicated which posture participants should adopt, and the experimenter collecting responses ensured that participants maintained the appropriate posture throughout each block. The order of postures was randomized across blocks. The first block for each posture in a task served as practice, and data from these blocks were not analyzed.

Experiment 2

An additional 60 volunteers from the same participant pool participated in Experiment 2 for course credit. All had normal or corrected-to-normal vision, and none had taken part in Experiment 1. The procedure of Experiment 2 was identical to that of Experiment 1 with the following exceptions: Instead of adopting a hands-near posture in which the backs of the hands rested near the display, participants in the second experiment adopted a little-fingers-near posture in which they extended the little finger of each hand and rested the tips of these fingers on the sides of the display (see Fig. 1b). These participants also trained with a different grasp task, repeatedly using the tips of their little fingers to pluck a small bean from a container full of beans and then drop the bean into a cup resting on one of the 10 target locations (see Fig. 2b). This type of task would normally involve using the thumb and forefinger in a typical precision grasp (e.g., Toibana, Ishikawa, & Sakakibara, 2002), so performing this task with the tips of the little fingers taught participants that they could use this atypical posture to successfully carry out a precision-grasp action goal. After transferring a bean, participants rested their hands in their laps before the experimenter indicated the next target location. The grasp training lasted 6 min. As in Experiment 1, participants in Experiment 2 performed eight blocks each of the motion and form tasks before grasp training and an additional eight blocks of each task following grasp training. Participants performed half of all blocks in the little-fingers-near posture and half in the same hands-far control posture employed in Experiment 1.

Results

Experiment 1

I calculated the mean percentage of signal dots at threshold for each participant before and after the novel power-grasp training for each combination of visual processing task and hand-posture condition. Figure 3 displays the means across participants. These scores were submitted to a 2 (time: before vs. after training) × 2 (task: motion detection vs. form perception) × 2 (hand posture: backs of hands near vs. hands far) analysis of variance (ANOVA). This analysis revealed significant main effects of time, $F(1, 59) = 8.21$, $p < .01$, $\eta_p^2 = .122$, and task, $F(1, 59) = 17.52$, $p < .01$, $\eta_p^2 = .229$; significant interactions between time and hand posture, $F(1, 59) = 4.51$, $p = .038$, $\eta_p^2 = .071$, and between task and hand posture, $F(1, 59) = 6.78$, $p = .012$, $\eta_p^2 = .103$; and, most crucially, a significant three-way interaction of time, task, and hand posture, $F(1, 59) = 7.13$, $p = .010$, $\eta_p^2 = .108$ (all other *p*s > .1). Bonferroni-adjusted post hoc pairwise comparisons examined performance differences between the two hand-posture conditions separately for the motion and form tasks both before and after training. These tests indicated that performance differed significantly depending on the hands' positioning only on the posttraining motion-detection task, $t(59) = 3.75$, $p < .01$ (all other adjusted *p*s > .1).

To better understand this three-way interaction and visualize how grasp training changed participants' performance, I calculated each participant's change in

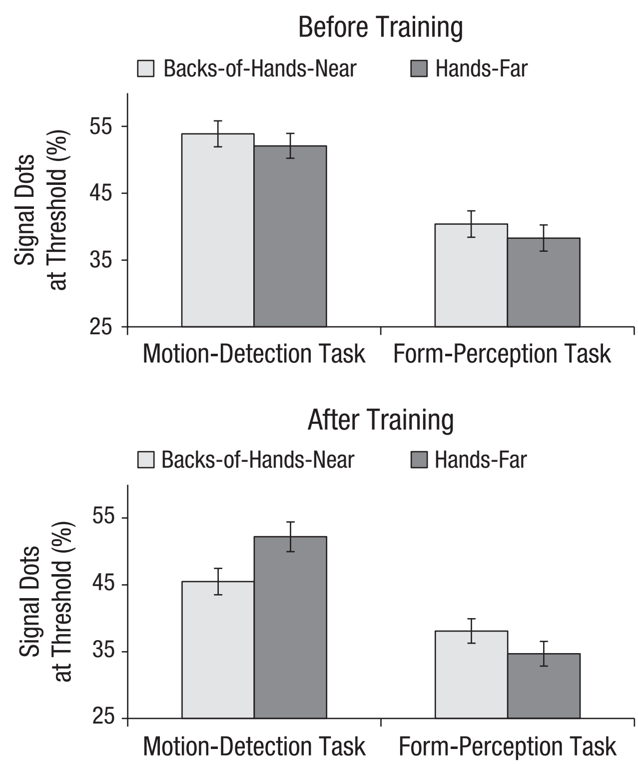

Fig. 3. Results from Experiment 1: mean percentage of signal dots present at the motion-coherence threshold in the motion-detection task and at the form-coherence threshold in the form-perception task. The results are shown separately for the two hand-posture conditions before and after training. Error bars represent ±1 *SEM*, calculated within subjects.

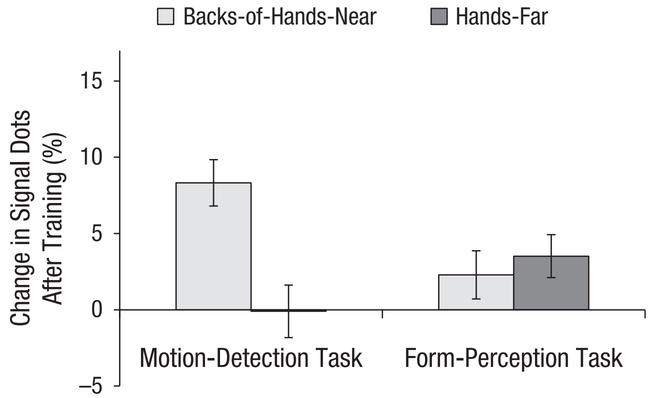

Fig. 4. Results from Experiment 1: mean change in the percentage of signal dots at threshold (pretraining minus posttraining) in the motion-detection and form-perception tasks. The results are shown separately for the two hand-posture conditions. Error bars represent ±1 *SEM*, calculated within subjects.

threshold (pretraining threshold minus posttraining threshold) in each task in each hand-posture condition. Thus, positive scores indicated greater sensitivity following training. As Figure 4 shows, although participants' sensitivity on the motion-detection task improved substantially in the backs-of-hands-near condition following grasp training, training made little difference to performance on the motion-detection task in the hands-far condition or on the form-perception task in either hand-posture condition. Bonferroni-adjusted post hoc one-sample *t* tests confirmed these impressions, indicating that the change in performance was significantly different from zero only in the backs-of-hands-near condition of the motion-detection task, $t(59) = 3.94$, $p < .01$ (all other adjusted *p*s > .1).

Experiment 2

An experimenter error resulted in the failure to record a complete data set for 2 participants in Experiment 2; these participants were dropped from analyses. An additional 2 participants were dropped from analyses for failing to use their little fingers appropriately during the grasp-training session of the experiment.

Figure 5 displays the mean percentage of signal dots at threshold before and after training for each task in each hand-posture condition. As in Experiment 1, these scores were submitted to a 2 (time: before vs. after training) × 2 (task: motion detection vs. form perception) × 2 (hand posture: little fingers near vs. hands far) ANOVA. This analysis revealed significant main effects of time, $F(1, 55) = 13.19$, $p < .01$, $\eta_p^2 = .193$; task, $F(1, 55) = 11.34$, $p < .01$, $\eta_p^2 = .171$; and hand posture, $F(1, 55) = 4.41$, $p = .040$, $\eta_p^2 = .074$. In addition, the interaction between time and task was significant, $F(1, 55) = 8.04$, $p < .01$, $\eta_p^2 = .128$; the interaction between time and hand posture was marginally significant, $F(1, 55) = 3.39$, $p = .071$, $\eta_p^2 = .058$; and the three-way interaction of time, task, and hand posture was marginally significant, $F(1, 55) = 3.45$, $p = .068$, $\eta_p^2 = .059$ (all other *p*s > .5). Bonferroni-adjusted post hoc pairwise comparisons between performance in the little-fingers-near and hands-far conditions for both tasks before and after training indicated that the hands' positioning led to a significant difference in performance only when the form-perception task was performed after training, $t(55) = 3.33$, $p < .01$ (all other adjusted *p*s > .1).

As in Experiment 1, I calculated each participant's posttraining change in the percentage of signal dots at threshold for each task in each hand-posture condition. As Figure 6 shows, participants were more sensitive on the form-perception task after training than they were before training when they held their little fingers near the display. Bonferroni-adjusted post hoc one-sample *t* tests confirmed that, although the change in performance following training was significantly different from zero in the little-fingers-near condition for the form-perception task, $t(55) = 5.99$, $p < .01$, participants' performance did not improve substantially on this task in the hands-far

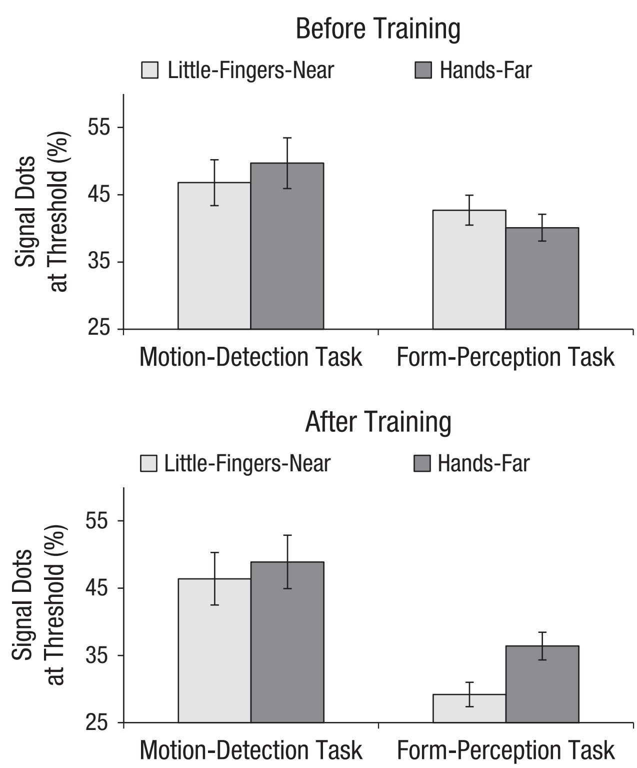

Fig. 5. Results from Experiment 2: mean percentage of signal dots present at the motion-coherence threshold in the motion-detection task and at the form-coherence threshold in the form-perception task. The results are shown separately for the two hand-posture conditions before and after training. Error bars represent ±1 *SEM*, calculated within subjects.

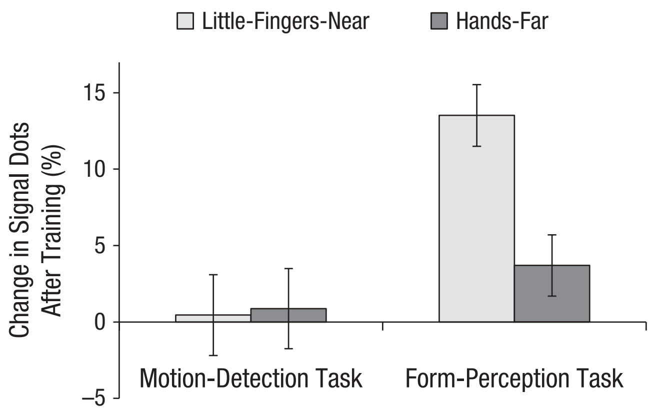

Fig. 6. Results from Experiment 2: mean change in the percentage of signal dots at threshold (pretraining minus posttraining) in the motion-detection and form-perception tasks. The results are shown separately for the two hand-posture conditions. Error bars represent ±1 *SEM*, calculated within subjects.

condition or on the motion-detection task in either of the hand-posture conditions (all other adjusted *p*s > .1).

A comparison of Figures 4 and 6 highlights a striking difference between Experiments 1 and 2 in the influence of grasp training on performance of the motion-detection and form-perception tasks. To directly examine this difference, I submitted participants' scores for the change in signal dots at threshold to a 2 × 2 × 2 mixed ANOVA with within-subjects factors of task (motion detection vs. form perception) and hand posture (hands or fingers near vs. hands far) and a between-subjects factor of experiment (1 vs. 2). This analysis yielded significant main effects of task, $F(1, 114) = 4.05$, $p = .046$, $\eta_p^2 = .034$, and hand posture, $F(1, 114) = 7.52$, $p < .01$, $\eta_p^2 = .062$; a significant interaction between task and experiment, $F(1, 114) = 7.48$, $p < .01$, $\eta_p^2 = .062$; and, most important, a significant three-way interaction of task, hand posture, and experiment, $F(1, 114) = 9.35$, $p < .01$, $\eta_p^2 = .076$ (all other *p*s > .1). Training with the novel power grasp led to increased temporal sensitivity in Experiment 1, whereas training with the novel precision grasp led to increased spatial sensitivity in Experiment 2. Grasp training led to changes in how participants processed stimuli presented near their hands, but the nature of these changes depended on the type of grasp on which participants trained.

Discussion

Across two experiments, I found evidence that training in using different types of novel grasps led participants to show improvements in sensitivity to different types of visual information viewed near their hands. In Experiment 1, participants' temporal sensitivity near the backs of their hands was enhanced after training to use this part of their hands in a novel power grasp. However, in Experiment 2, participants' spatial sensitivity near the tips of their little fingers was enhanced after training to use their little fingers in a novel precision grasp. Taken together, these findings provide evidence that recent action experience drives altered vision near the hands, weighting processing in favor of information relevant to newly practiced grasp affordances: Learned power-grasp postures facilitate processing of temporal visual information that will aid in fast and forceful actions, whereas learned precision-grasp postures lead to increased fine spatial sensitivity for more effective detail-oriented actions. This work demonstrates an unprecedented level of cross talk between vision and action, illustrating a remarkable plasticity of the visual-processing system to accommodate action.

It is important to note that in both experiments and on both tasks, participants' performance prior to training was similar regardless of whether their hands were positioned near or far from the display. These results are consistent with previous investigations suggesting that visual biases do not automatically occur near the hands if objects are presented outside of the hands' typical grasping space (e.g., Reed et al., 2010). Also of importance is the fact that participants showed virtually no improvement in performance following training in the hands-far condition: Simply training with an atypical power or precision grasp did not extend benefits in processing information relevant to the trained action to regions outside of peripersonal space. Instead, participants specifically showed greater sensitivity after training only when they viewed action-relevant information presented near their hands. Together with the absence of a near-hand bias prior to training, these results show that a brief training session essentially created a new zone of grasping space surrounding the hands—space the visual system evaluated in an affordance-specific manner. Although previous work has demonstrated that a short session of practice with a simple movement can lead to rapid transient remapping of motor cortex (e.g., Classen, Liepert, Wise, Hallett, & Cohen, 1998), and that several days of training with an awkward grasp using the dominant hand can alter the extent to which the grasp is susceptible to visual illusions (Gonzalez, Ganel, Whitwell, Morrissey, & Goodale, 2008), the current research provides the first evidence for short-term motor-driven plasticity in visual processing.

A popular account of altered vision near the hands posits that viewing information near hands positioned to afford a typical power grasp biases processing toward increased contribution from the high-temporal-resolution M pathway at the expense of the high-spatial-resolution P pathway (e.g., Abrams & Weidler, 2014). Although the current results are not inconsistent with this claim, they also suggest that visual biases are more malleable than this standard pathways hypothesis suggests. It seems that function may trump form when it comes to altered vision near the hands. When an observer experiences an affordance for a power grasp—regardless of the hands' exact posture—processing may be biased toward the M pathway, whereas any affordance for a precision grasp may instead weight processing toward increased contributions from the P pathway. The current results are also potentially consistent with an attentional account of altered vision near the hands (e.g., Bush & Vecera, 2014), which suggests that power-grasp affordances encourage a broader focus of attention consistent with temporal sensitivity whereas precision-grasp affordances instead create a tighter focus of attention that favors spatial sensitivity. Although future work is necessary to delineate the neural underpinnings of visual biases in perihand space, the current results suggest that any theory of altered vision near the hands must consider action experience and affordances.

Action Editor

Alice J. O'Toole served as action editor for this article.

Author Contributions

L. E. Thomas is the sole author of this article and is responsible for its content.

Acknowledgments

I thank Hallie Anderson, Katelynn Cox, Alissa Gordon, Morgan Jacoby, Maren Lack, Jessica Stelter, and Zainah Haider for their assistance with data collection.

Declaration of Conflicting Interests

The author declared that she had no conflicts of interest with respect to her authorship or the publication of this article.

Funding

This material is based on work supported by the National Science Foundation under Grant BCS 1556336 and by a Google Faculty Research Award.

Open Practices

All data have been made publicly available via the Open Science Framework and can be accessed at https://osf.io/tqzkd/. The complete Open Practices Disclosure for this article can be found at http://pss.sagepub.com/content/by/supplemental-data. This article has received the badge for Open Data. More information about the Open Practices badges can be found at https://osf.io/tvyxz/wiki/1.%20View%20the%20Badges/ and http://pss.sagepub.com/content/25/1/3.full.

Notes

1. A power analysis based on a moderate effect size ($d = 0.4$) derived from previous research (Thomas, 2015) revealed that 55 participants were needed to achieve 95% power. To account for the possibility of missing data or dropped participants, I ran an additional 5 participants. For both Experiments 1 and 2, data collection stopped after 60 participants were tested.

2. This manipulation potentially introduced a subtle confound: In the hands-near condition, participants' hands were positioned somewhat awkwardly, whereas in the hands-far condition, the hands were positioned relatively naturally. However, previous research has found that atypical positioning of the arms and hands does not drive visual biases near the hands (Davoli, Feng, Montana, Garverick, & Abrams, 2010; Weidler & Abrams, 2013). In addition, data from the pretraining blocks of this experiment suggest that this potential difference in comfort between the hands-near and hands-far postures did not lead to performance differences.

References

Abrams, R. A., Davoli, C. C., Du, F., Knapp, W. K., & Paull, D. (2008). Altered vision near the hands. *Cognition*, *107*, 1035–1047.

Abrams, R. A., & Weidler, B. J. (2014). Trade-offs in visual processing for stimuli near the hands. *Attention, Perception, & Psychophysics*, *73*, 383–390.

Brainard, D. H. (1997). The Psychophysics Toolbox. *Spatial Vision*, *10*, 433–436.

Brockmole, J. R., Davoli, C. C., Abrams, R. A., & Witt, J. K. (2013). The world within reach: Effects of hand posture and tool use on visual cognition. *Current Directions in Psychological Science*, *22*, 38–44.

Bush, W. S., & Vecera, S. P. (2014). Differential effect of one versus two hands on visual processing. *Cognition*, *133*, 232–237.

Classen, J., Liepert, J., Wise, S. P., Hallett, M., & Cohen, L. G. (1998). Rapid plasticity of human cortical movement representation induced by practice. *Journal of Neurophysiology*, *79*, 1117–1123.

Cosman, J. D., & Vecera, S. P. (2010). Attention affects visual perceptual processing near the hand. *Psychological Science*, *21*, 1254–1258.

Davoli, C. C., Feng, D., Montana, J., Garverick, S., & Abrams, R. A. (2010). When meaning matters, look but don't touch: The effects of posture on reading. *Memory & Cognition*, *38*, 555–562.

Glass, L. (1969). Moire effect from random dots. *Nature*, *223*, 578–580.

Gonzalez, C. L. R., Ganel, T., Whitwell, R. L., Morrissey, B., & Goodale, M. A. (2008). Practice makes perfect, but only with the right hand: Sensitivity to perceptual illusions with awkward grasps decreases with practice in the right but not the left hand. *Neuropsychologia*, *46*, 624–631.

Goodhew, S. C., & Clarke, R. (2016). Contributions of parvocellular and magnocellular pathways to visual perception near the hands are not fixed, but can be dynamically altered. *Psychonomic Bulletin & Review*, *23*, 156–162.

Gozli, D. G., West, G. L., & Pratt, J. (2012). Hand position alters vision by biasing processing through different visual pathways. *Cognition*, *124*, 244–250.

Iriki, A., Tanaka, M., & Iwamura, Y. (1996). Coding of modified body schema during tool use by macaque postcentral neurons. *NeuroReport*, *7*, 2325–2330.

Kelly, S. P., & Brockmole, J. R. (2014). Hand proximity differentially affects visual working memory for color and orientation in a binding task. *Frontiers in Psychology*, *5*, Article 318. doi:10.3389/fpsyg.2014.00318

Kleiner, M., Brainard, D., & Pelli, D. (2007). What's new in Psychtoolbox-3? [Abstract]. *Perception, 36*(1 Suppl.), 14.

Napier, J. R. (1956). The prehensile movements of the human hand. *The Journal of Bone and Joint Surgery*, *38*, 902–913.

Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision*, *10*, 437–442.

Reed, C. L., Betz, R., Garza, J. P., & Roberts, R. J. (2010). Grab it! Biased attention in functional hand and tool space. *Attention, Perception, & Psychophysics*, *72*, 236–245.

Reed, C. L., Grubb, J. D., & Steele, C. (2006). Hands up: Attentional prioritization of space near the hand. *Journal of Experimental Psychology: Human Perception and Performance*, *32*, 166–177.

Rosenbaum, D. A., Halloran, E. S., & Cohen, R. G. (2006). Grasping movement plans. *Psychonomic Bulletin & Review*, *13*, 918–922.

Soliman, T. M., Ferguson, R., Dexheimer, M. S., & Glenberg, A. M. (2015). Consequences of joint action: Entanglement with your partner. *Journal of Experimental Psychology: General*, *144*, 873–888.

Sun, H.-M., & Thomas, L. E. (2013). Biased attention near another's hand following joint action. *Frontiers in Psychology, 4*, Article 443. doi:10.3389/fpsyg.2013.00443

Taylor, J. E. T., Gozli, D. G., Chan, D., Huffman, G., & Pratt, J. (2015). A touchy subject: Advancing the modulated visual pathways account of altered vision near the hand. *Translational Neuroscience*, *6*, 1–7.

Thomas, L. E. (2013). Grasp posture modulates attentional prioritization of space near the hands. *Frontiers in Psychology, 4*, Article 312. doi:10.3389/fpsyg.2013.00312

Thomas, L. E. (2015). Grasp posture alters visual processing biases near the hands. *Psychological Science*, *26*, 625–632.

Toibana, N., Ishikawa, N., & Sakakibara, H. (2002). Measurement of manipulative dexterity in patients with hand-arm vibration syndrome. *International Archives of Occupational and Environmental Health*, *75*, 106–110.

Tseng, P., & Bridgeman, B. (2011). Improved change detection with nearby hands. *Experimental Brain Research*, *209*, 257–269.

Tseng, P., Bridgeman, B., & Juan, C. H. (2012). Take the matter into your own hands: A brief review of the effect of nearby-hands on visual processing. *Vision Research*, *72*, 74–77.

Weidler, B. J., & Abrams, R. A. (2013). Hand proximity—not arm posture—alters vision near the hands. *Attention, Perception, & Psychophysics*, *75*, 650–653.