Tracking moving objects

Alex O. Holcombe

Updated on 2021-03-11

Contents

Preface

This mini-book was written primarily for publication as a Cambridge Element. It should be cited as:

Holcombe, A.O. (to appear). Tracking moving objects. Cambridge University Press.

You can read this on the web here, as a PDF file, or as an e-book, which you can import into your Kindle or other e-book reader. However, the web version is the only one you should rely on - some features (e.g. movies, some kinds of images) may be missing from the other formats.

Contact me (he/him) with any comments via twitter or email - alex.holcombe@sydney.edu.au

Chapter 1

Two brains or one?

The fact that the brain is made up of two separate hemispheres has some striking consequences for object tracking , and more subtle ones for other tasks involving keeping objects in mind. This section will review the research regarding the remarkable hemifield independence of multiple object tracking (including two papers from my lab), as well as the specificity for spatial attention tasks - non-spatial measures of working memory show little independence, implicating a more unitary resource.

NOBODY has incorporated the hemifield division in their model!

Most people know that the brain has two hemispheres. Many know little else about the brain, but they understandably assume that the division of the brain into two halves has major consequences for how we learn. A major industry of pseudoscientific education consultants and brain training programs has sprung up around ideas such as "left brain versus right brain" training (**?**). The truth is that while early sensory processing is very hemisphere-specific, more cognitive functions such as explicit learning benefit from remarkably tight integration of the two hemispheres. When we open our eyes, we have the experience of attending easily to objects in any part of the visual field. We experience no dislocation when the movement of our eyes, or of an object, cause it to shift from one hemifield, where it is processed by one hemisphere, to the other hemifield, where it is processed by the other hemisphere. Communication between the two hemispheres happens rapidly and continuously. There is little to no evidence that exercises designed to insure both hemispheres process stimuli have any benefit for learning.

For those extraordinarily rare individuals who have had some connections between their hemispheres cut ("split brain" patients), the hemispheres act more independently. For tasks including searching for a target among many distractor objects, it is better to distribute the distractors across the two hemifields. Spreading the load in this way yields a large benefit for search, suggesting that

both hemispheres can search independently and simultaneously. (**?**). But for normal individuals, no such advantage is seen, suggesting that the processes that evaluate each stimulus for whether it is the target are well integrated across the hemispheres (**?**). Yet for a few tasks, normal individuals act much more as if their hemispheres are working independently.

In visual short-term memory tasks, people perform a good deal better when the stimuli are spread across both the left and right hemifields rather than all presented to the left hemifield or to the right hemifield (**?**). The reason, it is believed, is that there is some sort of resource that is specific to each hemifield. It is better, then, to spread one's load, rather than burdening one hemisphere more than the other. If the processes that limit memory performance were entirely specific to the hemispheres, then once people's limit for remembering objects presented to one hemifield were reached, one could add more objects to the other hemifield without any cost for the proportion of objects remembered. Instead, though, the hemifield advantage is only partial. There are a few tasks, however, for which the hemifield advantage seems to be complete, and multiple object tracking is one.

?: "a color and spatial location change detection task, in which the items were displayed either in the two visual fields or in the same hemifield. The data revealed that only memory capacity for spatial locations and not colors increased when the items were separated between the two visual fields. These findings support the view of VSTM as a chain of capacity limited operations where the spatial selection of stimuli, which dominates in both spatial location VSTM and MOT, occupies the first place and shows independence between the two fields."

? were the first to show that distributing objects to two hemifields rather than one could, essentially, double performance, as if two brains were doing the task rather than one…

? multiple identity tracking , found a hemifield advantage: " Contrary to expectations, a bilateral advantage was still observed, though it was not as strong as when observers were not required to remember the identities of the targets. This finding is inconsistent with the only model of multiple identity tracking (Oksama & Hyönä, 2008, Cognitive Psychology, 56, 237-283), so we present an alternative account."

?

RIGHT HEMIFIELD IS BETTER **?** (Figure A2), Battelli

1.0.1 Quadrants

Carlson et al. found evidence for quadrants. Has this been replicated? And **?** found a cost for crossing the vertical midline but not the horizontal midline. So now we know that the cross-hemisphere cost does not occur for quadrants.

Bibliography

Allen, R., Mcgeorge, P., Pearson, D. G., and Milne, A. (2006). Multiple-target tracking: A role for working memory? *Quarterly journal of experimental psychology*, 59(6):1101–1116.

Alston, L. and Humphreys, G. (2004). Subitization and attentional engagement by transient stimuli. *Spatial vision*, 17(1-2):17–50.

Alvarez, G. A. and Cavanagh, P. (2005). Independent resources for attentional tracking in the left and right visual hemifields. *Psychological Science*, 16(8):637–643.

Alvarez, G. A. and Franconeri, S. L. (2007). How many objects can you track? Evidence for a resource-limited attentive tracking mechanism. *Journal of Vision*, 7(13):14.1–10.

Bettencourt, K. C., Michalka, S. W., and Somers, D. C. (2011). Shared filtering processes link attentional and visual short-term memory capacity limits. *Journal of Vision*, 11(10):22–22.

Bill, J., Pailian, H., Gershman, S. J., and Drugowitsch, J. (2020). Hierarchical structure is employed by humans during visual motion perception. *Proceedings of the National Academy of Sciences*.

Bouma, H. (1970). Interaction effects in parafoveal letter recognition. *Nature*, 226(5241):177–178.

Carter, O. L., Burr, D. C., Pettigrew, J. D., Wallis, G. M., Hasler, F., and Vollenweider, F. X. (2005). Using psilocybin to investigate the relationship between attention, working memory, and the serotonin 1A and 2A receptors. *Journal of Cognitive neuroscience*, 17(10):1497–1508.

Cavanagh, P., Holcombe, A. O., and Chou, W. (2008). Mobile computation: Spatiotemporal integration of the properties of objects in motion. *Journal of Vision*, 8(12):1.1–23.

Chesney, D. L. and Haladjian, H. H. (2011). Evidence for a shared mechanism used in multiple-object tracking and subitizing. *Attention, Perception, & Psychophysics*, 73(8):2457–2480.

Davis, G. and Holmes, A. (2005). Reversal of object-based benefits in visual attention. *Visual Cognition*, 12(5):817–846.

Delvenne, J. (2012). Visual short-term memory and the bilateral field advantage.

Delvenne, J.-F. (2005). The capacity of visual short-term memory within and between hemifields. *Cognition*, 96(3):B79–88.

Doran, M. M. and Hoffman, J. E. (2010). The role of visual attention in multiple object tracking: Evidence from ERPs. *Attention, Perception, & Psychophysics*, 72(1):33–52.

Drew, T. and Vogel, E. K. (2008). Neural measures of individual differences in selecting and tracking multiple moving objects. *Journal of Neuroscience*, 28(16):4183–4191.

Duncan, J. (1984). Selective attention and the organization of visual information. *Journal of Experimental Psychology: General*, 113(4):501–517.

Eayrs, J. and Lavie, N. (2018). Establishing individual differences in perceptual capacity. *Journal of Experimental Psychology: Human Perception and Performance*, 44(8):1240.

Egly, R., Driver, J., and Rafal, R. D. (1994). Shifting visual attention between objects and locations: Evidence from normal and parietal lesion subjects. *Journal of Experimental Psychology: General*, 123(2):161.

Fencsik, D. E., Klieger, S. B., and Horowitz, T. S. (2007). The role of location and motion information in the tracking and recovery of moving objects. *Perception & psychophysics*, 69(4):567–77.

Fortenbaugh, F. C., DeGutis, J., Germine, L., Wilmer, J. B., Grosso, M., Russo, K., and Esterman, M. (2015). Sustained Attention Across the Life Span in a Sample of 10,000: Dissociating Ability and Strategy. *Psychological Science*, 26(9):1497–1510.

Fougnie, D. and Marois, R. (2006). Distinct Capacity Limits for Attention and Working Memory: Evidence From Attentive Tracking and Visual Working Memory Paradigms. *Psychological Science*, 17(6):526–534.

Franconeri, S. L., a Alvarez, G., and Enns, J. T. (2007). How many locations can be selected at once? *Journal of experimental psychology. Human perception and performance*, 33(5):1003–12.

Franconeri, S. L., Jonathan, S. V., and Scimeca, J. M. (2010). Tracking multiple objects is limited only by object spacing, not by speed, time, or capacity. *Psychological science*, 21(7):920–925.

Franconeri, S. L., Lin, J. Y., Pylyshyn, Z. W., Fisher, B., and Enns, J. T. (2008). Evidence against a speed limit in multiple-object tracking. *Psychonomic Bulletin & Review*, 15(4):802–808.

Gurnsey, R., Roddy, G., and Chanab, W. (2011). Crowding is size and eccentricity dependent. *Journal of vision*, 11:1–17.

Harris, D. J., Wilson, M. R., Crowe, E. M., and Vine, S. J. (2020). Examining the roles of working memory and visual attention in multiple object tracking expertise. *Cognitive Processing*, 21(2):209–222.

Hedge, C., Powell, G., and Sumner, P. (2018). The reliability paradox: Why robust cognitive tasks do not produce reliable individual differences. *Behavior Research Methods*, 50(3):1166–1186.

Hogben, J. H. and di Lollo, V. (1974). Perceptual integration and perceptual segregation of brief visual stimuli. *Vision research*, 14(11):1059–1069.

Holcombe, A. O., Chen, W., and Howe, P. D. L. (2014). Object tracking: Absence of long-range spatial interference supports resource theories. *Journal of Vision*, 14(6):1–21.

Holcombe, A. O. and Chen, W.-Y. (2012). Exhausting attentional tracking resources with a single fast-moving object. *Cognition*, 123(2).

Howard, C. J., Masom, D., and Holcombe, A. O. (2011). Position representations lag behind targets in multiple object tracking. *Vision research*, pages 1–13.

Howard, C. J., Pole, R., Montgomery, P., Woodward, A., Guest, D., Standen, B., Kent, C., and Crowe, E. M. (2020). Visual spatial attention and spatial working memory do not draw on shared capacity-limited core processes. *Quarterly Journal of Experimental Psychology*, 73(5):799–818.

Howe, P. D. and Holcombe, A. O. (2012). Motion information is sometimes used as an aid to the visual tracking of objects. *Journal of vision*, 12(13):10–10.

Howe, P. D., Incledon, N. C., and Little, D. R. (2012). Can attention be confined to just part of a moving object? Revisiting target-distractor merging in multiple object tracking. *PloS one*, 7(7):e41491.

Howe, P. D. L., Holcombe, A. O., Lapierre, M. D., and Cropper, S. J. (2013). Visually tracking and localizing expanding and contracting objects. *Perception*, 42(12):1281–1300.

Howe, P. D. L., Pinto, Y., and Horowitz, T. S. (2010). The coordinate systems used in visual tracking. *Vision research*, 50(23):2375–80.

Huang, L., Mo, L., and Li, Y. (2012). Measuring the interrelations among multiple paradigms of visual attention: An individual differences approach. *Journal of experimental psychology: human perception and performance*, 38(2):414.

Hudson, C., Howe, P. D., and Little, D. R. (2012). Hemifield effects in multiple identity tracking. *PloS one*, 7(8):e43796.

Hulleman, J. (2005). The mathematics of multiple object tracking: From proportions correct to number of objects tracked. *Vision Research*, 45(17):2298–2309.

Intriligator, J. and Cavanagh, P. (2001). The spatial resolution of visual attention. *Cognitive Psychology*, 43(3):171–216.

Jevons, W. S. (1871). *The Power of Numerical Discrimination*. Nature Publishing Group.

Joo, S. J., White, A. L., Strodtman, D. J., and Yeatman, J. D. (2018). Optimizing text for an individual's visual system: The contribution of visual crowding to reading difficulties. *Cortex*, 103:291–301.

Korte, W. (1923). über die Gestaltauffassung im indirekten Sehen. *Zeitschrift für Psychologie*, 93:17–82.

Kroeze, K., Hyatt, K. J., and Lambert, M. C. (2016). Brain Gym: Pseudoscientific Practice. *Journal of the American Academy of Special Education Professionals*.

Lou, H., Lorist, M. M., and Pilz, K. S. (2020). Individual differences in the temporal dynamics of object-based attention and the rhythmic sampling of visual space.

Luck, S. J., Hillyard, S. A., Mangun, G. R., and Gazzaniga, M. S. (1989). Independent hemispheric attentional systems mediate visual search in split-brain patients. *Nature*, 342(6249):543–545.

Luck, S. J., Hillyard, S. A., Mangun, G. R., and Gazzaniga, M. S. (1994). Independent attentional scanning in the separated hemispheres of split-brain patients. *Journal of cognitive neuroscience*, 6(1):84–91.

Lukavský, J. and Děchtěrenko, F. (2016). Gaze position lagging behind scene content in multiple object tracking: Evidence from forward and backward presentations. *Attention, Perception, & Psychophysics*, 78(8):2456–2468.

Mäki-Marttunen, V., Hagen, T., Laeng, B., and Espeseth, T. (2019). Distinct Neural Mechanisms Meet Challenges in Dynamic Visual Attention due to Either Load or Object Spacing. *Journal of Cognitive Neuroscience*, 32(1):65–84.

Mangine, G. T., Hoffman, J. R., Wells, A. J., Gonzalez, A. M., Rogowski, J. P., Townsend, J. R., Jajtner, A. R., Beyer, K. S., Bohner, J. D., Pruna, G. J., Fragala, M. S., and Stout, J. R. (2014). Visual Tracking Speed Is Related to Basketball-Specific Measures of Performance in NBA Players:. *Journal of Strength and Conditioning Research*, 28(9):2406–2414.

Mareschal, I., Morgan, M. J., and Solomon, J. A. (2010). Attentional modulation of crowding. *Vision Research*, 50(8):805–809.

Meyerhoff, H. S. and Papenmeier, F. (2020). Individual differences in visual attention: A short, reliable, open-source, and multilingual test of multiple object tracking in PsychoPy. *Behavior Research Methods*, 52(6):2556–2566.

Nakayama, K., He, Z. J., and Shimojo, S. (1995). Visual surface representation: A critical link between lower-level and higher-level vision. *Visual cognition: An invitation to cognitive science*, 2:1–70.

Oberauer, K. (2002). Access to information in working memory: Exploring the focus of attention. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 28(3):411.

O'Hearn, K., Hoffman, J. E., and Landau, B. (2010). Developmental profiles for multiple object tracking and spatial memory: Typically developing preschoolers and people with Williams syndrome. *Developmental Science*, 13(3):430–440.

Oksama, L. and Hyönä, J. (2004). Is multiple object tracking carried out automatically by an early vision mechanism independent of higher-order cognition? An individual difference approach. *Visual Cognition*, 11(5):631–671.

Papenmeier, F., Meyerhoff, H. S., Jahn, G., and Huff, M. (2014). Tracking by location and features: Object correspondence across spatiotemporal discontinuities during multiple object tracking. *Journal of Experimental Psychology: Human Perception and Performance*, 40(1):159.

Pashler, H. (1994). Dual-task interference in simple tasks: Data and theory. 116(2):220–244.

Petrov, Y. and Meleshkevich, O. (2011). Asymmetries and idiosyncratic hot spots in crowding. *Vision research*, 51(10):1117–1123.

Piazza, M. (2011). Neurocognitive start-up tools for symbolic number representations. *Space, time and number in the brain*, pages 267–285.

Pylyshyn, Z. (2004). Some puzzling findings in multiple object tracking: I. Tracking without keeping track of object identities. *Visual cognition*, 11(7):801–822.

Pylyshyn, Z. W. (2006). Some puzzling findings in multiple object tracking (MOT): II. Inhibition of moving nontargets. *Visual Cognition*, 14(2):175–198.

Pylyshyn, Z. W. and Storm, R. W. (1988). Tracking multiple independent targets: Evidence for a parallel tracking mechanism. 3(3):179–197.

Railo, H. (2014). Bilateral and two-item advantage in subitizing. *Vision Research*, 103:41–48.

Reichle, E. D., Liversedge, S. P., Pollatsek, A., and Rayner, K. (2009). Encoding multiple words simultaneously in reading is implausible. *Trends in Cognitive Sciences*, 13(February):115–119.

Revkin, S. K., Piazza, M., Izard, V., Cohen, L., and Dehaene, S. (2008). Does subitizing reflect numerical estimation? *Psychological science*, 19(6):607–614.

Sàenz, M., Buraĉas, G. T., and Boynton, G. M. (2003). Global feature-based attention for motion and color. *Vision research*, 43(6):629–37.

Scholl, B. (2001). Objects and attention: The state of the art. *Cognition*, 80(1/2):1–46.

Scholl, B. J., Pylyshyn, Z. W., and Feldman, J. (2001). What is a visual object? Evidence from target merging in multiple object tracking. *Cognition*, 80(1-2):159–77.

Sears, C. R. and Pylyshyn, Z. W. (2000). Multiple object tracking and attentional processing. *Canadian journal of experimental psychology = Revue canadienne de psychologie expérimentale*, 54(1):1–14.

Shomstein, S. and Behrmann, M. (2008). Object-based attention: Strength of object representation and attentional guidance. *Perception & psychophysics*, 70(1):132–144.

Shomstein, S. and Yantis, S. (2002). Object-based attention: Sensory modulation or priority setting? *Perception & psychophysics*, 64(1):41–51.

Simon, H. A. (1969). *The Sciences of the Artificial, Reissue of the Third Edition with a New Introduction by John Laird*. MIT Press Academic, Cambridge, MA, 3rd edition edition.

Souza, A. S. and Oberauer, K. (2017). The contributions of visual and central attention to visual working memory. *Attention, Perception, & Psychophysics*, 79(7):1897–1916.

Strasburger, H. (2014). Dancing letters and ticks that buzz around aimlessly: On the origin of crowding. *Perception*, 43(9):963–976.

Strong, R. W. and Alvarez, G. (2019). Hemifield-specific control of spatial attention and working memory: Evidence from hemifield crossover costs. Preprint, PsyArXiv.

Treviño, M., Zhu, X., Lu, Y. Y., Scheuer, L. S., Passell, E., Huang, G. C., Germine, L. T., and Horowitz, T. S. Bridging Cognitive and Neuropsychological Measures of Attention. *Cognitive Research: Principles and Implications*.

Trick, L. M., Audet, D., and Dales, L. (2003). Age differences in enumerating things that move: Implications for the development of multiple-object tracking. *Memory & Cognition*, 31(8):1229–1237.

Trick, L. M., Mutreja, R., and Hunt, K. (2012). Spatial and visuospatial working memory tests predict performance in classic multiple-object tracking in young adults, but nonspatial measures of the executive do not. *Attention, Perception, & Psychophysics*, 74(2):300–311.

Van der Burg, E., Cass, J., and Theeuwes, J. (2019). Changes (but not differences) in motion direction fail to capture attention. *Vision Research*, 165:54–63.

Wannig, A., Stanisor, L., and Roelfsema, P. R. (2011). Automatic spread of attentional response modulation along Gestalt criteria in primary visual cortex. *Nature neuroscience*, 14(10):1243–1244.

White, A. L. and Carrasco, M. (2011). Feature-based attention involuntarily and simultaneously improves visual performance across locations. *Journal of Vision*, 11(6):1–10.

White, A. L., Palmer, J., and Boynton, G. M. (2018). Evidence of serial processing in visual word recognition. *Psychological science*, 29(7):1062–1071.

Wolfe, J. M. and Bennett, S. C. (1997). Preattentive object files: Shapeless bundles of basic features. *Vision research*, 37(1):25–43.

Wolfe, J. M., Place, S. S., and Horowitz, T. S. (2007). Multiple object juggling: Changing what is tracked during extended multiple object tracking. *Psychonomic bulletin & review*, 14(2):344–9.

Wolford, G. (1975). Perturbation model for letter identification. *Psychological review*, 82(3):184.

Yantis, S. (1992). Multielement visual tracking: Attention and perceptual organization. *Cognitive psychology*, 24(3):295–340.

Zylberberg, A., Fernández Slezak, D., Roelfsema, P. R., Dehaene, S., and Sigman, M. (2010). The brain's router: A cortical network model of serial processing in the primate brain. *PLoS computational biology*, 6(4):e1000765.