



Visual Motion Perception, Visual Attention And Visual Information Processing

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13. ABSTRACT (Maximum 200 Words)

Continuing work on the three-systems-theory of visual motion perception: (1) Isoluminant chromatic motion is perceived by and only by the third-order motion system. (2) New illusion. Cancelling salience modulation in the third-order motion system causes brightly colored moving red-green gratings to appear to be motionless (motion standstill illusion) that gives considerable insight into the mechanisms of object perception. (3) A prediction that motion could be used to provide amplification of apparent contrast was verified, with amplifications >5x. (4) Amplification procedures were used to construct purified stimuli to stimulate each motion system individually, and (5) to measure the amplification produced by selective attention to a feature. (6) Developed computational models of attentional amplification of features and of the movement dynamics of spatial attention. The spatial attentional model was investigated with a new paradigm (gating spatial attention) to enable measurements of iconic memory uncontaminated by attention dynamics and to demonstrate that a new attention "window" open concurrently at all points within the window. (7) The spatial attention model predicts 90% of the variance in a huge data set (approximately 500 points per observer from >20,000 trials) and encompasses the major attention paradigms. (All items plus more are fully described in publications.)

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ABSTRACT

Continuing work on the three-systems-theory of visual motion perception: (1) Isoluminant chromatic motion is perceived by and only by the third-order motion system. (2) New illusion. Cancelling salience modulation in the third-order motion system causes brightly colored moving red-green gratings to appear to be motionless (motion standstill illusion) that gives considerable insight into the mechanisms of object perception. (3) A prediction that motion could be used to provide amplification of apparent contrast was verified, with amplifications $>5x$. (4) Amplification procedures were used to construct purified stimuli to stimulate each motion system individually, and (5) to measure the amplification produced by selective attention to a feature. (6) Developed computational models of attentional amplification of features and of the movement dynamics of spatial attention. The spatial attentional model was investigated with a new paradigm (gating spatial attention) to enable measurements of iconic memory uncontaminated by attention dynamics and to demonstrate that a new attention "window" open concurrently at all points within the window. (7) The spatial attention model predicts 90% of the variance in a huge data set (approximately 500 points per observer from $>20,000$ trials) and encompasses the major attention paradigms. (All items plus more are fully described in publications.)

Table of Contents

Cover page
Abstract; Table of Contents
Overview of Accomplishments
Publications 1997-2002
Talks at Symposia and Meetings of Professional Societies
Invited Lectures at Universities and Institutes
Honors

Published abstracts
Publications

OVERVIEW OF ACCOMPLISHMENTS

The main accomplishments during the current grant period in outline (see accompanying articles for details):

1. Discovery and proof that isoluminant motion is detected by the third-order motion system (PNAS, 1999a). A consequence of this is that the theory of third-order motion predicted it would be possible to produce motion standstill.

2. Motion standstill. Because third-order motion is assumed to depend on the space-time content of the salience field, reducing the salience modulation should eliminate third-order motion. In a red-green isoluminant grating moving on a white surround, salience is determined by the saturation of the colors, i.e., the difference between the red and green stripes from the background white. By careful, individual adjustment of the saturation ratio $|G|/|R|$ motion standstill was produced for every subject for a wide range of spatial and temporal frequencies of red-green gratings. These intensely colored, rapidly or slowly moving gratings, appear to be motionless (PNAS, 1999a, 1999c).

3. Pattern vision. In normal vision, the intrinsic instability of the eye causes the retinal image to jitter over long retinal distances relative to image details that are easily perceived. The phenomenon of motion standstill clarifies that visual pattern recognition systems which receive relatively rapidly moving, jittering inputs of an object, distill these many related images into a single output image of the object. How this is accomplished is the next major theme to be investigated.

4. Since the publication in 1995 of the Lu-Sperling three-systems theory of visual motion perception, it has aroused considerable interest and controversy. Eight major critiques have been published, plus many confirmatory studies. All of the studies are reconsidered. Four of the critiques (Victor, Carney, Smith, Strohmeyer) required considerable additional experiments and/or calculations in order to be fully understood. With the additional experimentation and with re-analysis, all the known criticisms were resolved, and there are no remaining contradictions. Our book-length review of this effort (JOSA, 2001) concludes that the three-systems theory has been significantly strengthened.

5. A paradigm using the amplification principle in motion perception was developed to produce "pure" stimuli, i.e., stimuli that are directed, for example, only to one motion system and that do not stimulate any other system. This method can produce stimuli which are directed specifically to one system, and in which unintended crosstalk between systems is reduced to less than a specifiable (typically tiny) fraction of threshold (Vision Research, 2001). This is an extremely sensitive assay method that has many other applications.

6. The sensitive motion-calibration method provides a convenient assay of the effects of selective attention. This was used to measure the salience amplification produced by selective attention to a color, e.g., red or green. Attention was found to produce about a 30% increase in the salience of a color (the exact value varies from subject-to-subject), with little effect on the color's appearance (PNAS, 1999b).

7. Demonstrating that the effect of attention is to change the "salience" of an attended item or location without changing its appearance is an important theoretical idea in interpreting experimental results. The distinction between salience and appearance -- that only salience is amplified by attention -- is an idea that appears to be poorly

understood, especially by neuroscientists measuring the effect of attention in single unit recordings and in brain imaging (fMRI, EEG). (The implications of the three-systems motion theory and of the effects of attention on brain imaging are beyond the scope of the current grant.)

8. The effect of selective attention to features in altering the salience of the attended features (versus their appearance) is the "engine" of a computational model that was developed to account for the color-amplification data (PNAS, 1999b). The computational model of selective-attention-to-feature involves similar mechanisms as the model for selective-attention-to-location.

9. A huge, long-standing project with Shui-I Shih, formerly a graduate student with the PI, now a lecturer at the University of Southampton, UK, was completed and is now in press in Psychological Review. A new paradigm was developed for measuring the full time-course of a movement of visual attention. Previous paradigms were repeated with the same subjects to produce a data base in which, for each subject, there were about 500 data points (based on more than 20,000 trials). Using the new results, it was possible to extract a measure of iconic memory (very short-term visual memory) that was uncontaminated by the time taken to shift attention. All the data together defined an elaborated, fully-computational model of visual attention that applies to all the major attention paradigms and accounts for about 90% of the variance in the data. It is argued that a computational model that makes more than 500 predictions establishes a new standard for psychological theories of attention, comparable to standards for theories in classical physics.

George Sperling 1997-2002

- Publications (including published abstracts)
- Talks at symposia and meetings of professional societies
- Invited lectures at universities and institutes

HIP Lab Publications 1997-2002

- 1997 Lu, Z-L, Sperling, G., and Beck, J. R. (1997). Selective adaptation of three motion systems. *Investigative Ophthalmology and Visual Science*, 38 (4), ARVO Abstract Book--Part 1, S237. (Abstract)
- 1997 Sperling, G, and Lu, Z-L. (1997). Proving the independence of first- and second-order motion systems. *Investigative Ophthalmology and Visual Science*, 38 (4), ARVO Abstract Book--Part 1, S237. (Abstract)
- 1997 Chubb, C., Lu, Z.-L., and Sperling, G. (1997). Statistically certified unsupervised learning. *Investigative Ophthalmology and Visual Science*, 38 (4), ARVO Abstract Book--Part 1, S257. (Abstract)
- 1997 Blaser, E., Sperling, G., and Lu, Z.-L. (1997). Measuring the spatial resolution of visual attention. *Investigative Ophthalmology and Visual Science*, 38 (4), ARVO Abstract Book--Part 2, S687. (Abstract)
- 1997 Sperling, G. (1997). The goal of theory in experimental psychology. In R. L. Solso (Ed.), *Mind and Brain Sciences in the 21st Century*. Cambridge, MA: MIT Press. Pp. 253-264.
- 1997 Chubb, Charles, Lu, Zhong-Lin, and Sperling, George. (1997). Structure detection: A statistically certified unsupervised learning procedure. *Vision Research (Special Issue: The Vision of Natural and Complex Images)*, 37, 3343-3365.
- 1997 Sperling, G., and Shih, S. (1997). Measuring and modeling selective attention in early visual processing. *Abstracts of the Psychonomic Society*, 2, 18. (Abstract)
- 1998 Sperling, G, and Lu, Z-L. (1998). A systems analysis of visual motion perception. In *High-level motion processing*. Takeo Watanabe (Ed). Cambridge MA: MIT Press. 153-183.
- 1998 Sperling, G. (1998). The economics of attention. *Mathematical Social Sciences*, 35, 75-76. (Abstract)
- 1998 Doshier, Barbara A., and Sperling, G. (1998). A century of human information processing theory: Vision, attention, memory. In Julian Hochberg, Ed. *Perception and Cognition at Century's End*. New York, NY: Academic Press. Pp. 201-254.
- 1998 Blaser, E., and Sperling, G. (1998). Measuring attention to color using an equivalent chromaticity paradigm. *Investigative Ophthalmology and Visual Science*, 39 (4), ARVO Supplement, S687. (Abstract)
- 1998 Sperling, G., and Lu, Z.-L. (1998). Update on the three-motion-systems theory. *Investigative Ophthalmology and Visual Science*, 39 (4), ARVO Supplement, S461. (Abstract)
- 1998 Richman, S., and Sperling, G. (1998). Perception of line-segment textures. *Investigative Ophthalmology and Visual Science*, 39 (4), ARVO Supplement, S857. (Abstract)
- 1998 Sperling, G. (1998). First-order, second-order, and third-order motion systems. *Perception*, 27, supplement, 3. (Abstract)
- 1998 Sperling, G. and Shih, Shui-I. (1998). A mathematical theory of iconic memory and attention. *Journal of Mathematical Psychology*, 42 (4), 507-8. (Abstract)
- 1998 Sperling, G and Blaser, E. (1998). Measuring the amplification factor of attention to color. *Abstracts of the Psychonomic Society*, 2, 24. (Abstract)
- 1999 Lu, Zhong-Lin and Sperling, George. (1999). Second-order reversed phi. *Perception and Psychophysics*, 61, 1075-1088.

- 1999 Lu, Zhong-Lin, Lesmes, Luis A., and Sperling, George. (1999). The mechanism of isoluminant chromatic motion perception. *Proceedings of the National Academy of Sciences, USA, 96*, 8289-8294.
- 1999 Lesmes, L. A., Lu, Z-L., and Sperling, G. (1999). The mechanism of isoluminant motion perception is third-order motion. *Investigative Ophthalmology and Visual Science, 40 (4)*, S190, Abstract nr 1048. (Abstract)
- 1999 Lu, Z-L., and Sperling, G. (1999). The Amplification Principle in Motion Perception. *Investigative Ophthalmology and Visual Science, 40 (4)*, S199, Abstract nr 1047. (Abstract)
- 1999 Sperling, G., and Lu, Z-L. (1999). Unequal Representation of Black and White in Human Vision. *Investigative Ophthalmology and Visual Science, 40 (4)*, S200, Abstract nr 1051. (Abstract)
- 1999 Chubb, C., Lu, Z-L., and Sperling, G. (1999). Measuring the nonlinearity used to sense high temporal frequency second-order motion. *Investigative Ophthalmology and Visual Science, 40 (4)*, S424, Abstract nr 2240. (Abstract)
- 1999 Ho, C. E., and Sperling, G. (1999). Selecting second and third-order motion pathways. *Investigative Ophthalmology and Visual Science, 40 (4)*, S425, Abstract nr 2246. (Abstract)
- 1999 Lu, Z-L., Lesmes, L. A., and Sperling, G. (1999). Isoluminant chromatic motion perception: defining the mechanism. *Perception, 28, supplement, 28*. (Abstract)
- 1999 Sperling, G., and Lu, Z-L. (1999). The perceptual amplification of attention to color. *Perception, 28, supplement, 57*. (Abstract)
- 1999 Blaser, E., Sperling, G., and Lu, Z-L. (1999). Measuring the amplification of attention. *Proceedings of the National Academy of Sciences, USA, 96*, 8289-8294.
- 1999 Sperling, G., and Ho, C. E. (1999). Attention and other determinants of perceived direction in ambiguous stimuli. *Abstracts of the Psychonomic Society, 4*, 18. (Abstract)
- 1999 Sperling, G. (1999). Computational models of attention switching. *Abstracts of the Psychonomic Society, 4*, 30. (Abstract)
- 1999 Lu, Zhong-Lin, Lesmes, Luis A., and Sperling, George. (1999). Perceptual motion standstill in rapidly moving chromatic displays. *Proceedings of the National Academy of Sciences, USA, 96 (26)*, 15374-15379.
- 2000 Tseng, Chia-huei, Gobell, Joetta L., and Sperling, George. (2000). Sensitization to color: Induced by search, measured by motion. *Investigative Ophthalmology and Visual Science, 41 (4)*, S40, Abstract nr 207. (Abstract)
- 2000 Tse, Chi-Hang, Lu, Zhong-Lin, and Sperling, George. (2000). Attending to red and green concurrently in different areas reduces attentional capacity. *Investigative Ophthalmology and Visual Science, 41 (4)*, S42, Abstract nr 218. (Abstract)
- 2000 Sperling, George, Kim, Tae-Seong, and Lu, Zhong-Lin. (2000). Direction-reversal VEPs reveal signatures of first- and second-order motion. *Investigative Ophthalmology and Visual Science, 41 (4)*, S948, Abstract nr 1754. (Abstract)
- 2000 Lesmes, Luis A., Lu, Zhong-Lin, and Sperling, George. (2000). Motion standstill in rapidly moving chromatic displays. *Investigative Ophthalmology and Visual Science, 41 (4)*, S796, Abstract nr 4225. (Abstract)
- 2000 Gobell, Joetta L., Tseng, Chia-huei, and Sperling, George. (2000). Effect of scene orientation of depth perception: Trapeaoids, windsurfers, runways. *Investigative Ophthalmology and Visual Science, 41 (4)*, S948, Abstract nr 5041. (Abstract)

- 2000 Sperling, G., and Ho, C. E. (2000). Third-order versus first-order and second-order motion in ambiguous stimuli: Competition reveals temporal tuning functions, monocular/binocular, and the role of attention. *Perception, 29, supplement*, 83. (Abstract)
- 2000 Lu, Z-L, Lesmes, L. A., and Sperling, G. (2000). Motion standstill perceived from rapidly moving red-green gratings. *Perception, 29, supplement*, 83. (Abstract)
- 2000 Sperling, G. and Lu, Z-L. (2000). *The current status of the three-systems theory of visual motion perception. Conference Program: Optics for the New Millennium. OSA Annual Meeting and Exhibit 2000*, Washington, D.C: Optical Society of America. p. 52. (Abstract)
- 2001 Sperling, G., Reeves, A., Blaser, E., Lu, Z-L., and Weichselgartner, E. (2001). Two Computational Models of Attention. In J. Braun, C. Koch and Davis (Eds.), *Visual attention and cortical circuits*. Cambridge, MA: MIT Press. Pp. 177-214. + four color plates.
- 2001 Appelbaum, L. G., Lu, Z.-L., and Sperling, G. (2001). Contrast amplification in a texture discrimination task. *Investigative Ophthalmology and Visual Science, 42 (4)*, S315, Abstract nr 1704.
- 2001 (Abstract) Tseng, C.-H., Kim, H., Gobell, J. L., Lu, Z.-L., and Sperling, G. (2001). Motion standstill in rapidly moving stereoptic depth displays. *Investigative Ophthalmology and Visual Science, 42 (4)*, S504, Abstract nr 2720.
- 2001 (Abstract) Sperling, G., Kim, H, and Lu, Z-L. (2001). Is there interocular first-order motion? *Investigative Ophthalmology and Visual Science, 42 (4)*, S532, Abstract nr 2855.
- 2001 (Abstract) Kim, H, Lu, Z-L., and Sperling, G. (2001). Rivalry motion versus depth motion. *Investigative Ophthalmology and Visual Science, 42 (4)*, S736, Abstract nr 3947.
- 2001 (Abstract) Gobell, J. L., Tseng, C.-H., and Sperling, G. (2001). Characterizing the constraints on the spatial distribution of visual attention. *Investigative Ophthalmology and Visual Science, 42 (4)*, S944, Abstract nr 5056.
- 2001 (Abstract) Lesmes, L. A., Lu, Z.-L., Doshier, B., Sperling, G., and Posner, C. (2001). Intra- and cross-modal activation of attention gates. *Investigative Ophthalmology and Visual Science, 42 (4)*, S945, Abstract nr 5058. (Abstract)
- 2001 Lu, Z-L., and Sperling, G. (2001). Sensitive calibration and measurement procedures based on the amplification principle in motion perception. *Vision Research, 41*, 2355-2374.
- 2001 Tseng, C. and Sperling, G. (2001). Sensitization to color: Induced by instructions, measured by motion. *Proceedings of the Third International Conference on Cognitive Science*, Beijing, China: Press of University of Science and Technology of China, 286-287. (Abstract)
- 2001 Lu, Z-L., and Sperling, G. (2001). Three systems theory of human visual motion perception: review and update. *Journal of the Optical Society of America A: Optics and Image Science, 18*, 2331-2370.
- 2002 Shih, S. and Sperling, G. (2002). Measuring and modeling the trajectory of visual spatial attention. *Psychological Review*, 260-305.
- 2002 Lu, Z-L., and Sperling, G. (2002). Stereomotion is processed by the third-order motion system: Reply to comment. *Journal of the Optical Society of America A: Optics and Image Science, 19*, (In press).

George Sperling: Talks at Symposia and Meetings of Professional Societies 1997-2002

† Indicates an invited address.

†† Indicates a plenary address.

* Indicates an abstract of talk was published.

- 1997 Sperling, G. Twenty-Second Annual Interdisciplinary Conference, Jackson, Wyoming, February 4, 1997. *Real and Simulated Saccades; Real and Stroboscopic Motion.*
- 1997 †† Tagung experimentell arbeitender Psychologen, 39 TeaP (39th Conference of Experimental Psychologists), Humboldt University, Unter den Linden, Berlin, Germany. March 24-27, 1997. Plenary paper (March 26): *Atoms of the Mind: An Historic Overview of Theories of Attention.*
- 1997 *Sperling, G., and Lu, Z-L. Paper presented by G. Sperling. Association for Research in Vision and Ophthalmology, Fort Lauderdale, Florida, May 12, 1997. *Proving the Independence of First- and Second-Order Motion Systems*
- 1997 *Lu, Z-L and Sperling, G. Paper presented by Zhong-Lin Lu. Association for Research in Vision and Ophthalmology, Fort Lauderdale, Florida, May 12, 1997. *Selective Adaptation of Three Motion Systems.*
- 1997 *Blaser, E. and Sperling, G. Paper presented by E. Blaser. Association for Research in Vision and Ophthalmology, Fort Lauderdale, Florida, May 12, 1997. *Measuring the Spatial Resolution of Visual Attention.*
- 1997 *Chubb, C., Lu, Z-L, and Sperling, G. Paper presented by C. Chubb. Association for Research in Vision and Ophthalmology, Fort Lauderdale, Florida, May 12, 1997. *Statistically Certified Unsupervised Learning.*
- 1997 *Sperling, G., and Lu, Z-L. Paper presented by G. Sperling. Association for Research in Vision and Ophthalmology, Fort Lauderdale, Florida, May 12, 1997. *Proving the Independence of First- and Second-Order Motion Systems*
- 1997 † Workshop on Vision, Recognition, Action: Neural Models of Mind and Machine, Boston University, May 30, 1997. *An Integrated Theory for Attentional Processes in Vision, Recognition, and Memory.*
- 1997 *Sperling, G., and Shih, S. (1997). Paper presented by G. Sperling. Psychonomic Society, Philadelphia, PA., November 21, 1997. *Measuring and Modeling Selective Attention in Early Visual Processing.*
- 1998 Sperling, G. Twenty-Third Annual Interdisciplinary Conference, Jackson, Wyoming, February 2, 1998. *Update on the Three Systems Theory of Motion Perception.*
- 1998 94th Annual Meeting of the Society of Experimental Psychologists Laguna Beach, California, March 28, 1998. *Second-Order Perception.*
- 1998 *Sperling, G., and Lu, Z-L. (1998). Paper presented by G. Sperling. Association for Research in Vision and Ophthalmology, Fort Lauderdale, Florida, March 12, 1998. *Update on the Three-Motion-Systems Theory.*
- 1998 *Richman, S., and Sperling, G. Poster presented by S. Richman. Association for Research in Vision and Ophthalmology, Fort Lauderdale, Florida, March 13, 1998. *Perception of line-segment textures.*

- 1998 *Blaser, E., and Sperling, G. Paper presented by E. Blaser. Association for Research in Vision and Ophthalmology, Fort Lauderdale, Florida, May 14, 1998. *Measuring Attention to Color Using an Equivalent Chromaticity Paradigm.*
- 1998 †*European Conference on Visual Perception Oxford University, Oxford, England, August 25, 1998 *First- Second- and Third-Order Motion Systems.*
- 1998 †*Sperling, G. and Shih, S. (1998). Paper presented by G. Sperling. 29th European Mathematical Psychology Group Meeting Keele University, Keele, Staffordshire, England, September 1, 1998. *A Mathematical Theory of Iconic Memory and Attention.*
- 1998 *Sperling, G and Blaser, E. Paper presented by G. Sperling. Psychonomic Society, Dallas Texas, November 20, 1998. *Measuring and Modeling Selective Attention in Early Visual Processing.*
- 1999 †Catalina Workshop on Visual Attention and Neural Circuits. Sponsored by California Institute of Technology and The Office of Naval Research, Two Harbors, Catalina Island, January 8, 1999. *Computational Models of Attention.*
- 1999 Sperling, G. Twenty-Fourth Annual Interdisciplinary Conference, Jackson, Wyoming, February 1, 1999 *Tutorial Overview of Higher-Order Motion Systems.*
February 3, 1999 *Measuring the Amplification of Attention.*
- 1999 *Lesmes, L., Lu, Z-L., and Sperling, G. Paper presented by L. Lesmes, Association for Research in Vision and Ophthalmology, Fort Lauderdale, Florida, May 10, 1999. *The Mechanism of Isoluminant Motion Perception is Third-Order Motion.*
- 1999 *Lu, Z-L., and Sperling, G. Paper presented by G. Sperling, Association for Research in Vision and Ophthalmology, Fort Lauderdale, Florida, May 10, 1999. *The Amplification Principle in Motion Perception.*
- 1999 *Sperling, G., and Lu, Z-L. Paper presented by G. Sperling, Association for Research in Vision and Ophthalmology, Fort Lauderdale, Florida, May 10, 1999. *Unequal Representation of Black and White in Human Vision.*
- 1999 *Chubb, C., Lu, Z-L., and Sperling, G. Poster presented by C. Chubb, Association for Research in Vision and Ophthalmology, Fort Lauderdale, Florida, May 11, 1999. *Measuring the Nonlinearity Used to Sense High Temporal Frequency Second-Order Motion.*
- 1999 *Ho, C. E., and Sperling, G. Poster presented by G. Sperling, Association for Research in Vision and Ophthalmology, Fort Lauderdale, Florida, May 11, 1999. *Selecting Second and Third-Order Motion Pathways.*
- 1999 †International Conference on Vision and Attention, Centre for Vision Research, York University, June 22 -26, 1999. *Computational Models of Attention.*
- 1999 *Z-L. Lu, L. Lesmes, and G. Sperling. Paper presented by Z-L. Lu., The XXII European Conference on Visual Perception (ECVP), Trieste, Italy, August 24, 1999. *Isoluminant Chromatic Motion Perception: Defining the Mechanism.*
- 1999 *Sperling, G., Blaser, E., and Lu, Z-L. Paper presented G. Sperling, The XXII European Conference on Visual Perception (ECVP), Trieste, Italy, August 26, 1999. *The Perceptual Amplification of Attention to Color.*
- 1999 †*Sperling, G., Lesmes, L., Lu, Z-L, paper presented by G. Sperling. 31st European Mathematical Psychology Group Meeting, University of Mannheim, Germany, Symposium in Honor of Jan Drosler. August 30, 1999. *A theory of isoluminant chromatic motion perception.*
- 1999 †Symposium to Honor Samuel J. Williamson, New York University, Department of Physics and Center for Neuroscience. September 24, 1999. *Neuromagnetism and Short-Term Memory: Auditory and Visual*

- 1999 *Sperling, G. Psychonomic Society, Los Angeles, CA, November 19, 1999. *Computational Models of Attention Switching*.
- 1999 *Sperling, G, and Ho, C. E. Psychonomic Society, Los Angeles, CA, November 19, 1999. *Attention and other determinants of perceived direction in ambiguous stimuli*.
- 2000 Sperling, G. Twenty-Fifth Annual Interdisciplinary Conference, Jackson, Wyoming, January 26, 2000 *The Mechanisms of Visual Attention*.
- 2000 *Tseng, Chia-huei, Gobell, Joetta L., and Sperling, George. (2000). Poster. Association for Research in Vision and Ophthalmology, Fort Lauderdale, Florida, April 30, 2000. *Sensitization to color: Induced by search, measured by motion*.
- 2000 *Tse, Chi-Hang, Lu, Zhong-Lin, and Sperling, George. (2000). Poster. Association for Research in Vision and Ophthalmology, Fort Lauderdale, Florida, April 30, 2000. *Attending to red and green concurrently in different areas reduces attentional capacity*.
- 2000 *Sperling, George, Kim, Tae-Seong, and Lu, Zhong-Lin. (2000). Association for Research in Vision and Ophthalmology, Fort Lauderdale, Florida, May 2, 2000. *Direction-reversal VEPs reveal signatures of first- and second-order motion*.
- 2000 *Lesmes, Luis A., Lu, Zhong-Lin, and Sperling, George. (2000). Poster. Association for Research in Vision and Ophthalmology, Fort Lauderdale, Florida, May 4, 2000. *Motion standstill in rapidly moving chromatic displays*.
- 2000 *Gobell, Joetta L., Tseng, Chia-huei, and Sperling, George. (2000). Paper presented by J. L. Gobell, Association for Research in Vision and Ophthalmology, Fort Lauderdale, Florida, May 5, 2000. *Effect of scene orientation of depth perception: Trapeaoids, windsurfers, runways*.
- 2000 *Sperling, G., and Ho, C. E. (2000). The XXIII European Conference on Visual Perception (ECVP), Groningen, The Netherlands August 30, 2000. *Third-order versus first-order and second-order motion in ambiguous stimuli: Competition reveals temporal tuning functions, monocular-ity/binocularity, and the role of attention*.
- 2000 *Lu, Z-L, Lesmes, L. A., and Sperling, G. (2000). The XXIII European Conference on Visual Perception (ECVP), Groningen, The Netherlands August 30, 2000. *Motion standstill perceived from rapidly moving red-green gratings*.
- 2000 †*Sperling, G. Optical Society of America, Providence, Rhode Island, †Symposium: First-, Second-, Third-Order Mechanisms of Pattern and Motion Perception, October 22. *The current status of the three-systems theory of visual motion perception*.
- 2000 †Sperling, G. Optical Society of America, Providence, Rhode Island, Workshop on Chromatic Motion Mechanisms, October 23. *The mechanism of isoluminant red-green motion perception*
- 2000 ††*Sperling, G. International Congress of Neural Information Processing, Taejun, Korea. Plenary lecture, November 16, 2000. *Neural Computations in Early Vision*
- 2001 Appelbaum, L. Gregory, Lu, Zhong-Lin, and Sperling, George. (2001). Paper presented by C.-H. Tseng, Association for Research in Vision and Ophthalmology, Fort Lauderdale, Florida, May 1, 2001. *Contrast amplification in a texture discrimination task*.
- 2001 *Tseng, Chia-huei, Kim, Hyungjun, Gobell, Joetta L., Lu, Zhong-Lin, and Sperling, George. (2001). Paper presented by C.-H. Tseng, Association for Research in Vision and Ophthalmology, Fort Lauderdale, Florida, May 2, 2001. *Motion standstill in rapidly moving stereoptic depth displays*.
- 2001 *Sperling, G., Kim, H, and Lu, Z-L. (2001). Paper presented by H. Kim, Association for Research in Vision and Ophthalmology, Fort Lauderdale, Florida, May 2, 2001. *Is there interocular first-order motion?*

- 2001 *Kim, H, Lu, Z-L., and Sperling, G. (2001). Paper presented by H. Kim, Association for Research in Vision and Ophthalmology, Fort Lauderdale, Florida, May 3, 2001. *Rivalry motion versus depth motion.*
- 2001 *Gobell, Joetta L., Tseng, Chia-huei, and Sperling, George. (2001). Paper presented by J. L. Gobell, Association for Research in Vision and Ophthalmology, Fort Lauderdale, Florida, May 4, 2001. *Characterizing the constraints on the spatial distribution of visual attention.*
- 2001 *Lesmes, Luis A., Lu, Zhong-Lin, Doshier, Barbara, Sperling, George, and Posner, C. (2001). Paper presented by L. A. Lesmes, Association for Research in Vision and Ophthalmology, Fort Lauderdale, Florida, May 4, 2001. *Intra- and cross-modal activation of attention gates.*
- 2001 †Sperling, G. 8th Joint Symposium on Neural Computation, The Salk Institute, La Jolla, California, May 19, 2001. *What motion standstill tells us about pattern perception.*
- 2001 ††*Sperling, G. International Conference on Cognitive Science, Beijing, China, Plenary lecture, August 27, 2001. *Computational models of visual selective attention to space and to features.*
- 2001 *Chia-Huei Tseng and George Sperling. Paper presented by C. Tseng. International Conference on Cognitive Science, Beijing, China August 27, 2001. *Sensitization to color: Induced by instructions, measured by motion*
- 2001 †*Sperling, G. Optical Society of America, UCI Satellite Meeting, University of California, Irvine, Workshop on Visual Attention, October 13, 2001, *Measuring the trajectory of visual attention.*
- 2001 *Appelbaum, L. G., Z-L. Lu and G. Sperling, Optical Society of America, UCI Satellite Meeting, University of California, Irvine, Poster, October 14, 2001, *Facilitation of Subthreshold Contrasts by Means of Texture-Slant.*
- 2001 *Gobell, J., C.H. Tseng, and G. Sperling, Optical Society of America, UCI Satellite Meeting, University of California, Irvine, Poster, October 14, 2001, *Measuring the spatial resolution of visual attention.*
- 2001 *Kim, Hyungjun, Zhong-Lin Lu, and George Sperling Optical Society of America, UCI Satellite Meeting, University of California, Irvine, Poster, October 14, 2001, *Rivalry motion: A cue to cyclopean motion perception.*
- 2001 *Tseng, Chia-Huei, Hyungjun Kim, Joetta L. Gobell, Zhong-Lin Lu, and George Sperling, Optical Society of America, UCI Satellite Meeting, University of California, Irvine, Poster, October 14, 2001, *Revisiting Stereoptic Motion Standstill: Stereoptic Motion Processing Has Lower Temporal Resolution than Shape Processing.*
- 2002 ††*Tagung experimentelle arbeiteneden Psychologie 44 (TeaP, 44th Conference of Experimental Psychologists), Technische Universitaet, Chemnitz, Chemnitz, Germany, Plenary lecture, March 26, 2002. *The three systems theory of motion perception.*
- 2002 98th Annual Meeting of the Society of Experimental Psychologists University of California, Berkeley April 6, 2002 *Third-Order Motion.*

Invited Lectures at Universities and Institutes 1997-2002

- 1997 Max Planck Institute, Munich, Germany. April 2, 1997. *Computational Review of Early Visual Processing.*
- 1997 Max Planck Institute, Tuebingen, Germany. April 3, 1997. *How to Experimentally Isolate Three Systems of Visual Motion Perception.*
- 1997 University of Houston, Houston, Texas, December 6, 1997.
 (1) College of Optometry, Seminar. *The Orders of Visual Motion--Techniques for Creating Pure Stimuli.*
 (2) Institute of Cognitive Sciences Distinguished Speakers Series. *Deriving a Function Architecture for Visual Motion Perception.*
- 1998 University of Wales (Bangor), Bangor, Gwynedd, Wales, UK, Institute of Cognitive Sciences, September 3, 1998. *Repetition Detection: A Paradigm for Measuring Attentional Filtering.*
- 1999 University of Freiburg, Freiburg, Germany, Departments of Neurology and Psychology, Joint Colloquium, September 1, 1999. *Three systems of Visual Motion Perception: Historical Review, Current Status.*
- 1999 University of California, Irvine, CA. 1999-2000 Distinguished Faculty Lectureship Award for Research, Lecture, University Club, November 15, 1999. *Modeling Human Motion Perception.*
- 2000 University of California, Berkeley, California, Department of Psychology Colloquium, March 3, 2000. *The three systems theory of motion perception: Review and Update.*
- 2000 University of Trier, Germany, Psychology Department Colloquium, September 7, 2000. *Measuring and modelling the dynamics of visual spatial attention.*
- 2000 University of California, Irvine, CA. Department of Cognitive Sciences Colloquium October 9, 2000. *Measuring and modeling the dynamics of visual spatial attention.*
- 2000 Rutgers, The State University, Busch Campus, Piscataway, New Jersey, Center for Cognitive Science Colloquia Series, October 24, 2000. *Measuring and modelling visual attention*
- 2000 The Catholic University of Korea, Puchon, Seoul, S. Korea, Department of Psychology, Special Interdepartmental Colloquium, November 20, 2000. *How the human brain computes motion.*
- 2001 Center for General Education, National Yang Ming University, Teipei, Republic of China.
 September 3 2001.
Computational models of visual attention to space and to features
 September 4 2001.
The three systems theory of human visual motion perception: Review and Update
- 2001 Human and Information Science Laboratory, NTT Communication Science Laboratories, NTT Corporation, Atsugi-shi, Kanayama, Japan. September 6, 2001. *The three systems theory of human visual motion perception: Review and Update*
- 2001 Department of Psychology, University of Tokyo, Bunkyo-ku, Tokyo, Japan. September 7, 2001. *The three systems theory of human visual motion perception: Review and Update*
- 2002 Institut fuer Allgemeine Psychologie, Universitaet Leipzig (Seeburgestr. 14-20, 04 103 Leipzig, Germany), March 27, 2002, *Measuring and Modeling the trajectory of visual spatial attention.*

George Sperling: HONORS 1997-2002

University of California, Academic Senate, Irvine Division. 1999-2000. *Distinguished Faculty Lectureship Award for Research*. (One awarded annually for outstanding research: "Distinguished lecture," reception, engraved plaque.)

Optical Society of America, 2002. *Edgar D. Tillyer Award*. "You are being recognized 'for your innovative research in human visual information processing, specifically in flicker perception, spatial vision, binocular vision, masking, visual memory, visual attention, and motion perception.'" (Awarded every two years: Silver medal, certificate, \$1,500.)

Plenary Lectures at International Conferences

Tagung experimentell arbeitender Psychologen, 39 TeaP (39th Conference of Experimental Psychologists), Humboldt University, Unter den Linden, Berlin, Germany. March 24-27, 1997. Plenary lecture (March 26). *Atoms of the Mind: An Historic Overview of Theories of Attention*.

International Congress of Neural Information Processing, Taejun, Korea. Plenary lecture, November 16, 2000. *Neural Computations in Early Vision*

International Conference on Cognitive Science, Beijing, China, Plenary lecture, August 27, 2001. *Computational Models of Visual Selective Attention to Space and to Features*.

Tagung experimentelle arbeitenden Psychologie 44 (TeaP, 44th Conference of Experimental Psychologists), Technische Universität, Chemnitz, Chemnitz, Germany, Plenary lecture, March 26, 2002. *The Three Systems Theory of Motion Perception*.