
SPR AWARD, 1999

For Distinguished Contributions to Psychophysiology: Steven A. Hillyard

At the Thirty-Ninth Annual Meeting of the Society for Psychophysiological Research (SPR), the award for Distinguished Contributions to Psychophysiology was presented to Steven A. Hillyard. The following is the citation given by Risto Näätänen on behalf of the Society's Awards Committee on October 9, 1999.

It is my extraordinarily pleasant duty to make an announcement of historical significance for our field, namely that the SPR has decided to give its award for Distinguished Contributions to Psychophysiology, its most prestigious award, to Steve Hillyard of the University of California, San Diego. Steve was born in California in 1942 and obtained his B.S. in Biology at the California Institute of Technology (Cal-Tech) in 1964. He received his Ph.D. from Yale University in 1968, this time in Psychology and under the guidance of Robert Galambos. When we add here the fact that during his undergraduate years at Cal Tech Steve served as a research assistant in Psychobiology under C.R. Hamilton and Nobel Laureate R.W. Sperry, it is obvious that the starting point of his scientific career was very fortunate. It appears that he received the best possible research training available in our field at that time. Even the most excellent training will not achieve good results, however, unless there is enough brain plasticity to receive and to make full use of the opportunity, as we all know. But Steve's brain did have enough plasticity, of course. His first article (Hillyard & Galambos, 1967), coauthored with his thesis advisor Robert Galambos, investigated the contingent negative variation (CNV), a research topic of central interest at that time. This article appeared in the *EEG Journal* in 1967, one year before he received his doctoral degree, and was soon followed by many, many others, at the highest level of excellence in our field.

As a student of Sperry and later as a collaborator of Michael Gazzaniga, it is natural that the hemispheric specialization of brain function was one of Steve's early research interests. These studies also belonged to the top rank of cognitive neuroscience in those days, but I do not believe that we do injustice to Steve if we give most of the credit for the excellence of these studies to those more senior colleagues Sperry and Gazzaniga rather than to Steve, whose major scientific innovations and pioneering research work came a little later.

The first manifestation of Steve as a principal investigator, group leader, and scientific innovator can be seen in an excellent series of analytical studies on event-related potential (ERP) correlates of the detection of weak auditory signals, carried out in collaboration with Nancy and Ken Squires and P.J. Lindsay. These works from the early 1970s are still standard references in that research area.

Steve's most important contribution to science, no doubt, is his extensive work on the electrophysiology of selective attention. It is here that our paths crossed. When we met in 1973 at the Bristol EPIC-3 Congress, organized by our beloved and, sadly, our late colleague and friend Cheyne McCallum, I told Steve that I had definitely ruled out the possibility that selective attention could enhance the auditory exogenous N1 component and that all the many people and studies claiming such an effect were certainly wrong. I tried to convince Steve that neither Nature nor God could have constructed the human brain in such a simplistic way. He countered, however, that he had been able to design an experimental paradigm that fully succeeded in meeting my severe criticism against the previous studies and that the N1 effect was still present. This classic article (Hillyard, Hink, Schwent, & Picton, 1973) appeared in *Science* in 1973 and was the starting point of our quarter-century quarrel over the nature of the selective-attention effect on the auditory N1 (Figure 1).

The issue at stake was certainly not trivial. For cognitive neuroscience, it is of the outmost importance to determine the lowest level of sensory-perceptual processing that can be modulated by means of voluntary efferent control. This is also the central issue for the competing theories of selective attention and information processing developed on the basis of behavioral data by cognitive psychologists such as Broadbent, Treisman, Deutsch, and Deutsch, and others.

So, Steve and I and our respective allies did not spend some of our best years in vain as we struggled to clarify these and related issues. The battle was intense but always fair, and it was never clear which side was going to win as the situation continually evolved. When we in Helsinki believed that at last we were able to deliver the final blow, we very soon noticed that we had become the target of an even stronger hit, and so the "missiles" crossed the Atlantic Ocean in both directions several times.

Now that the fighting has finally stopped and the dust has settled to the ground, we can see that both their N1 effect from 1973 (Hillyard et al., 1973) and our processing negativity (PN) from 1978 have survived. That is, selective attention can produce both types of effects on the auditory N1, and these effects can even occur in parallel and in good peace.

Indeed, both effects have subsequently been observed in both laboratories. One day during this fight the PN dared to show up in Steve's laboratory, which was reported in the excellent Hansen and Hillyard (1980) study. The San Diego investigators chose to avoid the term PN, however, and instead called their negative difference wave the Nd; but it turned out that the Nd was nothing more or less

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Figure 1. The discussion on the nature of the N1 effect of selective attention has started. From left to right: Risto Näätänen, Steven A. Hillyard, Terence W. Picton, and Emanuel Donchin. (International Evoked Potential Congress, Brussels, April 1974.)

than the PN difference between attended and unattended sounds, as was shown by my comrade in arms, Kimmo Alho.

So now that the dust has settled, we can see that we in Helsinki were not able to annihilate the N1 effect of selective attention. But, as mentioned previously, this battle was not fought in vain. Although Steve and I and our respective colleagues were antagonists in this controversy, from the larger perspective of cognitive psychophysiology and neuroscience, we were allies in an attempt to resolve one of the most fundamental and difficult issues in our field, namely the extent of voluntary attentional control of information processing and the mechanisms of this control. This intense but fair competition between the two opposing camps created optimal conditions of motivation and mutual creative stimulation. I believe that both sides have fared much better because of this game, which was interesting and attracted research money and excellent representatives of the new generation of cognitive electrophysiologists and neuroscientists such as Alho, Woldorff, Hansen, Teder, and many others who received their critical training in the crucible of these extensive research efforts.

In addition, many other groups have entered this field and made significant contributions to the key issues after being attracted by the ongoing vivid controversy and the progress made as both parties did their best to find the truth.

As for Steve's other work, his research on visual selective attention can be regarded as equally impressive and influential as his work on auditory selective attention and has become his main research area for the past 15 years or so. In the visual studies he has

been liberated from us to promote the type of explanation of selective-attention effects on ERPs that he favors, which I have termed the gain theory of selective attention, and here he has found nobody daring or able to challenge his interpretations. This type of theory suggests that selective attention when highly focused is powerful enough even to modulate the central stimulus representations underlying perception (which we believed was not the case in audition).

Most recently, Steve has also started to use methodologies of cognitive brain research other than electrophysiology, of course with success, as is the case with anything he tries, at least in science. Fortunately, however, it seems that he is and always will be loyal to electrophysiology, never forgetting the unique things that can be accomplished with it and with the closely related magnetoencephalography methodology but not with the newer techniques of brain imaging, which many believe will soon replace electrophysiology as an old-fashioned methodology belonging only to this millennium as far as top-level brain science is concerned. This belief will turn out to be an illusion, however, a misleading and dangerous illusion, because time is as important as space. One cannot exist without the other, irrespective of whether we think of such large ball-like entities as the earth and the planets or such small ball-like entities as the human head.

Steve's research career as a whole is really impressive and in many ways unique in our field. In addition to selective attention, his research has involved several other central issues in our field, always producing new, ingenious experimental paradigms and find-

ings that make remarkable, often pioneering, contributions to the field. Of his more than 150 articles that have appeared in international refereed journals, no fewer than 12 have appeared in *Nature* or *Science*, showing that the significance and import of his research has exceeded the traditional borders of interest of our field. One of the characteristics of Steve's research articles is the extreme lucidity, clarity, and elegance with which they are written. For years, this clarity of scientific communication has served as an unattainable but yet helpful model for others, including my group and me. Consistent with this, Steve is an excellent teacher at all levels, apparently because of his talent for clear expression, being able to anticipate and thus to avoid possible misunderstandings. Otherwise, he could not have obtained the UCSD Neuroscience

Department Outstanding Teacher Award, which he has, in fact, received four times! Also, otherwise he would not be one of the most successful teachers, trainers, and mentors of the next generation of cognitive psychophysiologicalists and neuroscientists, who will be taking over when Steve and I and our generation retire, if not earlier.

Ladies and Gentlemen, this time the choice of the recipient of the highest prize of SPR, the award for Distinguished Contributions to Psychophysiology, was very easy: Steve Hillyard!

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BIBLIOGRAPHY OF STEVEN A. HILLYARD (in chronological order)

- Hillyard, S. A., & Galambos, R. (1967). Effects of stimulus and response contingencies on a surface negative slow potential shift in man. *Electroencephalography and Clinical Neurophysiology*, 22, 297–304.
- Hamilton, C. R., Hillyard, S. A., & Sperry, R. W. (1968). Interhemispheric comparison of color in split-brain monkeys. *Experimental Neurology*, 21, 486–494.
- Hillyard, S. A. (1969). Relationships between the contingent negative variation (CNV) and reaction time. *Physiology and Behavior*, 4, 351–357.
- Hillyard, S. A. (1969). The CNV and the vertex evoked potential during signal detection: A preliminary report. In E. Donchin & D. B. Lindsley (Eds.), *Averaged evoked potentials: Methods, results, evaluations* (pp. 349–353). NASA SP-191. Washington, DC: NASA.
- Hillyard, S. A., & Dargent, J. (1969). Dimensions comportementales associées à des variations lentes du potentiel de repos cérébral. In J. Dargent & M. Dongier (Eds.), *Variations contingentes négatives* (Congrès et Colloques de l'Université de Liège, Vol. 52, pp. 215–230). Liège, France: Université de Liège.
- Hillyard, S. A., & Galambos, R. (1970). Eye movement artifact in the CNV. *Electroencephalography and Clinical Neurophysiology*, 28, 173–182.
- Galambos, R., & Hillyard, S. A. (1970). Determinants of neural and behavioral plasticity: An overview. In F. O. Schmitt (Ed.), *The neurosciences: Second study program* (pp. 289–297). New York: The Rockefeller University Press.
- Hillyard, S. A., Squires, K. C., Bauer, J. W., & Lindsay, P. H. (1971). Evoked potential correlates of auditory signal detection. *Science*, 172, 1357–1360.
- Picton, T. W., Hillyard, S. A., Galambos, R., & Schiff, M. (1971). Human auditory attention: A central or peripheral process? *Science*, 173, 351–353.
- Gazzaniga, M. S., & Hillyard, S. A. (1971). Language and speech capacity of the right hemisphere. *Neuropsychologia*, 9, 273–280.
- Picton, T. W., & Hillyard, S. A. (1972). Cephalic skin potentials in electroencephalography. *Electroencephalography and Clinical Neurophysiology*, 33, 419–424.
- Gazzaniga, M. S., & Hillyard, S. A. (1973). Attention mechanisms following brain bisection. In S. Kornblum (Ed.), *Attention and performance IV* (pp. 221–238). New York: Academic Press.
- Squires, K. C., Hillyard, S. A., & Lindsay, P. H. (1973). Cortical potentials evoked by feedback confirming and disconfirming an auditory discrimination. *Perception and Psychophysics*, 13, 25–31.
- Hillyard, S. A. (1973). The CNV and human behavior. In W. C. McCallum & J. R. Knott (Eds.), *Event-related slow potentials of the brain: Their relation to behavior* (pp. 161–171). Amsterdam: Elsevier.
- Squires, K. C., Hillyard, S. A., & Lindsay, P. L. (1973). Vertex potentials evoked during auditory signal detection: Relation to decision criteria. *Perception and Psychophysics*, 14, 265–272.
- Hillyard, S. A., Hink, R. F., Schwent, V. L., & Picton, T. W. (1973). Electrical signs of selective attention in the human brain. *Science*, 182, 177–180.
- Picton, T. W., Hillyard, S. A., Krausz, H. I., & Galambos, R. (1974). Human auditory evoked potentials. I: Evaluation of components. *Electroencephalography and Clinical Neurophysiology*, 36, 179–190.
- Picton, T. W., & Hillyard, S. A. (1974). Human auditory evoked potentials. II: Effects of attention. *Electroencephalography and Clinical Neurophysiology*, 36, 191–199.
- Hillyard, S. A. (1974). Methodological issues in CNV research. In R. F. Thompson & M. M. Patterson (Eds.), *Methods in physiological psychology: Vol. I. Recording of bioelectric activity* (pp. 281–304). New York: Academic Press.
- Picton, T. W., Hillyard, S. A., & Galambos, R. (1974). Cortical evoked responses to omitted stimuli. In M. N. Livanov (Ed.), *Major problems of brain electrophysiology* (pp. 302–311). Russia: USSR Academy of Science.
- Squires, K. C., Squires, N. K., & Hillyard, S. A. (1975). Vertex evoked potentials in a rating scale detection task: Relation to signal probability. *Behavioral Biology*, 13, 21–34.
- Schwent, V. L., & Hillyard, S. A. (1975). Auditory evoked potentials and multichannel selective attention. *Electroencephalography and Clinical Neurophysiology*, 38, 131–138.
- Squires, N. K., Squires, K. C., & Hillyard, S. A. (1975). Two varieties of long-latency positive waves evoked by unpredictable auditory stimuli. *Electroencephalography and Clinical Neurophysiology*, 38, 387–401.
- Squires, K. C., Squires, N. K., & Hillyard, S. A. (1975). Decision-related cortical potentials during an auditory signal detection task with cued observation intervals. *Journal of Experimental Psychology: Human Perception and Performance*, 104, 268–279.
- Courchesne, E., Hillyard, S. A., & Galambos, R. (1975). Stimulus novelty, task relevance and the visual evoked potential in man. *Electroencephalography and Clinical Neurophysiology*, 39, 131–143.
- Hillyard, S. A., Courchesne, E., Krausz, H. I., & Picton, T. W. (1976). Scalp topography of the "P3" wave in different auditory decision tasks. In W. C. McCallum & J. R. Knott (Eds.), *The responsive brain* (pp. 81–87). Bristol, UK: John Wright & Sons.
- Snyder, E., & Hillyard, S. A. (1976). Long-latency evoked potentials to irrelevant deviant stimuli. *Behavioral Biology*, 16, 319–331.
- Schwent, V. L., Hillyard, S. A., & Galambos, R. (1976). Selective attention and the auditory vertex potential. I: Effects of stimulus delivery rate. *Electroencephalography and Clinical Neurophysiology*, 40, 604–614.
- Schwent, V. L., Hillyard, S. A., & Galambos, R. (1976). Selective attention and the auditory vertex potential. II: Effects of signal intensity and masking noise. *Electroencephalography and Clinical Neurophysiology*, 40, 615–622.
- Schwent, V. L., Snyder, E., & Hillyard, S. A. (1976). Auditory evoked potentials during multichannel selective listening: Role of pitch and localization cues. *Journal of Experimental Psychology: Human Perception and Performance*, 2, 313–325.
- Picton, T. W., Hillyard, S. A., & Galambos, R. (1976). Habituation and attention in the auditory system. In W. Keidel, & W. Neff (Eds.), *Handbook of sensory physiology: Vol. 5/3. The auditory system* (pp. 343–389). Berlin, Germany: Springer-Verlag.
- Hink, R. F., & Hillyard, S. A. (1976). Auditory evoked potentials during selective listening to dichotic speech messages. *Perception and Psychophysics*, 20, 236–242.
- Hink, R. F., Van Voorhis, S. T., Hillyard, S. A., & Smith, T. S. (1977). The division of attention and the human auditory evoked potential. *Neuropsychologia*, 15, 597–605.
- Van Voorhis, S. T., & Hillyard, S. A. (1977). Visual evoked potentials and selective attention to points in space. *Perception and Psychophysics*, 22, 54–62.

- Courchesne, E., Courchesne, R. Y., & Hillyard, S. A. (1977). P3 waves to the discrimination of targets in homogeneous and heterogeneous stimulus sequences. *Psychophysiology*, *14*, 590–597.
- Hink, R. F., Hillyard, S. A., & Benson, P. J. (1978). Event-related brain potentials and selective attention to acoustic and phonetic cues. *Biological Psychology*, *6*, 1–16, 1978.
- Courchesne, E., Courchesne, R. Y., & Hillyard, S. A. (1978). The effect of stimulus deviation on P3 waves to easily recognized stimuli. *Neuropsychologia*, *16*, 189–199.
- Hillyard, S. A. (1978). Computer dissection of the auditory evoked potential: A comment on Schweitzer. *Perception and Psychophysics*, *23*, 549–552.
- Squires, N. K., Squires, K. C., & Hillyard, S. A. (1978). The functional equivalence of signal-present, signal absent, and threshold-detect P3's. In D. Otto (Ed.), *Multidisciplinary perspectives in event-related brain potential research* (EPA Publication No. 600/9-77-043, pp. 218–221). Washington, DC: U.S. Government Printing Office.
- Woods, D. L., & Hillyard, S. A. (1978). Attention at the cocktail party: Brainstem evoked responses reveal no peripheral gating. In D. A. Otto (Ed.), *Multidisciplinary perspectives in event-related brain potential research* (EPA 600/9-77-043, pp. 230–233). Washington, DC: U.S. Government Printing Office.
- Hink, R. F., & Hillyard, S. A. (1978). Electrophysiological measures of attentional processes in man as related to the study of schizophrenia. *Journal of Psychiatric Research*, *14*, 155–165.
- Hillyard, S. A., Picton, T. W., & Regan, D. (1978). Sensation, perception and attention: Analysis using ERPs. In E. Callaway, P. Tueting, & S. Koslow (Eds.), *Event-related brain potentials in man* (pp. 223–321). New York: Academic Press.
- Hillyard, S. A., & Picton, T. W. (1978). ON and OFF components in the auditory evoked potential. *Perception and Psychophysics*, *24*, 391–398.
- Hillyard, S. A., & Woods, D. L. (1979). Electrophysiological analysis of human brain function. In M. S. Gazzaniga (Ed.), *Handbook of behavioral neurobiology: Vol. II. Neuropsychology* (pp. 345–378). New York: Plenum Press.
- Hillyard, S. A., & Picton, T. W. (1979). Event-related brain potentials and selective information processing in man. In J. Desmedt (Ed.), *Progress in clinical neurophysiology: Vol. 6. Cognitive components in cerebral event-related potentials and selective attention* (pp. 1–50). Basel, Switzerland: Karger.
- Snyder, E., & Hillyard, S. A. (1979). Changes in visual event-related potentials in older persons. In F. Hoffmeister (Ed.), *Brain function in old age* (pp. 112–125). Bayer Symposium VII. Berlin, Germany: Springer-Verlag.
- Kutas, M., & Hillyard, S. A. (1980). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science*, *207*, 203–205.
- Woods, D. L., Hillyard, S. A., Courchesne, E., & Galambos, R. (1980). Electrophysiological signs of split-second decision making in man. *Science*, *207*, 655–656.
- Snyder, E., Hillyard, S. A., & Galambos, R. (1980). Similarities and differences among the P3 waves to detected signals in three modalities. *Psychophysiology*, *17*, 112–122.
- Hansen, J. C., & Hillyard, S. A. (1980). Endogenous brain potentials associated with selective auditory attention. *Electroencephalography and Clinical Neurophysiology*, *49*, 277–290.
- Knight, R. T., Hillyard, S. A., Woods, D. L., & Neville, H. J. (1980). The effects of frontal and temporal-parietal lesions on the auditory evoked potential in man. *Electroencephalography and Clinical Neurophysiology*, *50*, 112–124.
- Kutas, M., & Hillyard, S. A. (1980). Reading between the lines: Event-related brain potentials during natural sentence processing. *Brain and Language*, *11*, 354–373.
- Woods, D. L., Courchesne, E., Hillyard, S. A., & Galambos, R. (1980). Recovery cycles of event-related potentials in multiple detection tasks. *Electroencephalography and Clinical Neurophysiology*, *50*, 335–347.
- Woods, D. L., Courchesne, E., Hillyard, S. A., & Galambos, R. (1980). Split-second recovery of P3 component in multiple decision tasks. In H. H. Kornhuber & L. Deecke (Eds.), *Progress in brain research: Vol. 54. Motivation, motor and sensory processes of the brain: Electrical potentials, behaviour and clinical use* (pp. 322–330). Amsterdam: Elsevier.
- Kutas, M., & Hillyard, S. A. (1980). Event-related brain potentials to semantically inappropriate and surprisingly large words. *Biological Psychology*, *11*, 99–116.
- Hillyard, S. A. (1981). Selective auditory attention and early event-related potentials: A rejoinder. *Canadian Journal of Psychology*, *35*, 85–100.
- Ford, J. M., & Hillyard, S. A. (1981). Event-related potentials (ERPs) to interruptions of a steady rhythm. *Psychophysiology*, *18*, 322–330.
- Galambos, R., & Hillyard, S. A. (1981). Electrophysiological approaches to human cognitive processing. *Neurosciences Research Program Bulletin*, *20*, 141–265.
- Hillyard, S. A. (1981). Electrophysiological studies of attention. In M. Lansman & E. Hunt (Eds.), *Proceedings of the Lake Wilderness Attention Conference* (pp. 167–193). Office of Naval Research Technical Report No. 10. Arlington, VA: Office of Naval Research.
- Knight, R. T., Hillyard, S. A., Woods, D. L., & Neville, H. J. (1981). The effects of frontal cortex lesions on event-related potentials during auditory selective attention. *Electroencephalography and Clinical Neurophysiology*, *52*, 571–582.
- Hillyard, S. A., & Bloom, F. E. (1982). Brain functions and mental processes. In D. Griffin (Ed.), *Animal mind—Human mind* (pp. 13–32). Berlin, Germany: Springer-Verlag.
- Kutas, M., & Hillyard, S. A. (1982). The lateral distribution of event-related potentials during sentence processing. *Neuropsychologia*, *20*, 579–590.
- Hillyard, S. A. (1982). Psychobiology. In F. E. Bloom (Ed.), *The five-year outlook on science and technology* (pp. 33–43). Washington, DC: National Science Foundation.
- Hillyard, S. A., & Kutas, M. (1983). Electrophysiology of cognitive processing. *Annual Review of Psychology*, *34*, 33–61.
- Kutas, M., & Hillyard, S. A. (1983). Event-related brain potentials to grammatical errors and semantic anomalies. *Memory and Cognition*, *11*, 539–550.
- Hansen, J. C., & Hillyard, S. A. (1983). Selective attention to multidimensional auditory stimuli in man. *Journal of Experimental Psychology: Human Perception and Performance*, *9*, 1–19.
- Hansen, J. C., Dickstein, P. W., Berka, C., & Hillyard, S. A. (1983). Event-related potentials during selective attention to speech sounds. *Biological Psychology*, *16*, 211–229.
- Arnsten, A. F. T., Segal, D. S., Janowsky, D. S., Judd, L. L., Hillyard, S. A., Neville, H., & Bloom, F. E. (1983). Naloxone augments electrophysiological signs of selective attention in man. *Nature*, *304*, 725–727.
- Hillyard, S. A. (1984). Event-related potentials and selective attention. In E. Donchin (Ed.), *Cognitive psychophysiology: Event-related potentials and the study of cognition* (pp. 51–72). Hillsdale, NJ: Erlbaum.
- Hansen, J. C., & Hillyard, S. A. (1984). Effects of stimulation rate and attribute cueing on event-related potentials during selective auditory attention. *Psychophysiology*, *21*, 394–405.
- Kutas, M., & Hillyard, S. A. (1984). Brain potentials during reading reflect word expectancy and semantic association. *Nature*, *307*, 161–163.
- Kutas, M., & Hillyard, S. A. (1984). Event-related potentials in cognitive science. In M. S. Gazzaniga (Ed.), *Handbook of cognitive neuroscience* (pp. 387–409). New York: Plenum Press.
- Kutas, M., & Hillyard, S. A. (1984). Event-related brain potentials (ERPs) elicited by “novel” stimuli during sentence processing. In R. Karrer, J. Cohen, & P. Tueting (Eds.), *Annals of the New York Academy of Sciences: Vol. 425. Brain and information: Event-related potentials* (pp. 236–241). New York: New York Academy of Sciences.
- Kutas, M., Lindamood, T. E., & Hillyard, S. A. (1984). Word expectancy and event-related brain potentials during sentence processing. In S. Kornblum, & J. Requin (Eds.), *Preparatory states and processes* (pp. 217–237). Hillsdale, NJ: Erlbaum.
- Hillyard, S. A., Simpson, G. V., Woods, D. L., Van Voorhis, S., & Münte, T. (1984). Event-related brain potentials and selective attention to different modalities. In F. Reinoso-Suarez & C. Ajmone-Marsan (Eds.), *Cortical integration* (pp. 395–414). New York: Raven Press.
- Hillyard, S. A., & Münte, T. F. (1984). Selective attention to color and location: An analysis with event-related brain potentials. *Perception and Psychophysics*, *36*, 185–198.
- Hillyard, S. A. (1984). Cognitive functions and event-related brain potential. In R. H. Nodar & C. Barber (Eds.), *Evoked potentials II* (pp. 51–62). Stoneham, MA: Butterworth.
- Woods, D. L., Hillyard, S. A., & Hansen, J. C. (1984). Event-related brain potentials reveal similar attentional mechanisms during selective listening and shadowing. *Journal of Experimental Psychology: Human Perception and Performance*, *10*, 761–777.
- Arnsten, A. F. T., Neville, H. J., Hillyard, S. A., Janowsky, D. S., & Segal, D. S. (1984). Naloxone increases electrophysiological measures of selective information processing in man. *Journal of Neuroscience*, *4*, 2912–2919.

- Hillyard, S. A., Münte, T. F., & Neville, H. J. (1985). Visual-spatial attention, orienting and brain physiology. In M. I. Posner & O. S. Marin (Eds.), *Mechanisms of attention: Attention and performance XI* (pp. 63–84). Hillsdale, NJ: Erlbaum.
- Kutas, M., & Hillyard, S. A. (1985). Event-related potentials and psychopathology. In J. O. Cavenar, Jr. (Ed.), *Psychiatry* (Vol. 3, Chapter 62). Philadelphia: Lippincott/Harter & Row.
- Hillyard, S. A. (1985). Electrophysiology of human selective attention. *Trends in Neurosciences*, 8, 400–405.
- Hillyard, S. A., & Hansen, J. C. (1986). Attention: Electrophysiological approaches. In M. G. H. Coles, E. Donchin, & S. W. Porges (Eds.), *Psychophysiology: Systems, processes and applications* (pp. 227–243). New York: Guilford Press.
- Mangun, G. R., Hansen, J. C., & Hillyard, S. A. (1986). Electroretinograms reveal no evidence for centrifugal modulation of retinal inputs during selective attention in man. *Psychophysiology*, 23, 156–165.
- Hillyard, S. A., & Mangun, G. R. (1986). The neural basis of visual selective attention: A commentary on Harter and Aine. *Biological Psychology*, 23, 265–279.
- Hillyard, S. A., Woldorff, M., Mangun, G. R., & Hansen, J. C. (1987). Mechanisms of early selective attention in auditory and visual modalities. *Electroencephalography and Clinical Neurophysiology*, 39(Suppl.), 317–324.
- Mangun, G. R., & Hillyard, S. A. (1987). The spatial allocation of visual attention as indexed by event-related brain potentials. *Human Factors*, 29, 195–211.
- Hillyard, S. A., & Picton, T. W. (1987). Electrophysiology of cognition. In F. Plum (Ed.), *Handbook of physiology, Section 1: The nervous system. Volume V. Higher functions of the brain, Part 2* (pp. 519–584). Bethesda, MD: American Physiological Society.
- Hillyard, S. A. (1987). Event-related potentials and human information processing. In G. Adelman (Ed.), *Encyclopedia of neuroscience* (Vol. 1, pp. 409–411). Boston: Birkhauser.
- Hillyard, S. A., & Mangun, G. R. (1987). Sensory gating as a physiological mechanism for visual selective attention. In R. Johnson, J. Rohrbaugh, & R. Parasuraman (Eds.), *Current trends in event-related potential research. Electroencephalography and Clinical Neurophysiology*, 40(Suppl.), 61–67.
- Mangun, G. R., Hansen, J. C., & Hillyard, S. A. (1987). The spatial orienting of attention: Sensory facilitation or response bias? In R. Johnson, J. Rohrbaugh, & R. Parasuraman (Eds.), *Current trends in event-related potential research. Electroencephalography and Clinical Neurophysiology*, 40(Suppl.), 118–124.
- Woldorff, M., Hansen, J. C., & Hillyard, S. A. (1987). Evidence for effects of selective attention in the midlatency range of the human auditory event related potential. In R. Johnson, J. Rohrbaugh, & R. Parasuraman (Eds.), *Current trends in event-related potential research. Electroencephalography and Clinical Neurophysiology*, 40(Suppl.), 146–154.
- Hackley, S. A., Woldorff, M., & Hillyard, S. A. (1987). Combined use of microreflexes and event-related brain potentials as measures of auditory selective attention. *Psychophysiology*, 24, 632–647.
- Kutas, M., & Hillyard, S. A. (1988). Contextual effects in language comprehension: Studies using event-related brain potentials. In F. Plum (Ed.), *Language, communication and the brain* (pp. 87–100). New York: Raven Press.
- Picton, T. W., & Hillyard, S. A. (1988). Endogenous event-related potentials. In T. W. Picton (Ed.), *Handbook of electroencephalography and clinical neurophysiology: Vol. 3. Human event-related potentials* (pp. 361–426). Amsterdam: Elsevier.
- Hansen, J. C., & Hillyard, S. A. (1988). Temporal dynamics of human auditory selective attention. *Psychophysiology*, 25, 316–329.
- Kutas, M., Hillyard, S. A., & Gazzaniga, M. S. (1988). Processing of semantic anomaly by right and left hemispheres of commissurotomy patients: Evidence from event-related brain potentials. *Brain*, 111, 553–576.
- Hillyard, S. A. (1988). Experimental design considerations in studies of event-related potentials to word and nonword stimuli. *Perceptual and Motor Skills*, 66, 129–130.
- Mangun, G. R., & Hillyard, S. A. (1988). Spatial gradients of visual attention: Behavioral and electrophysiological evidence. *Electroencephalography and Clinical Neurophysiology*, 70, 417–428.
- Paller, K. A., Zola-Morgan, S., Squire, L. R., & Hillyard, S. A. (1988). P3-like brain waves in normal monkeys and monkeys with medial temporal lesions. *Behavioral Neuroscience*, 102, 714–725.
- Kutas, M., & Hillyard, S. A. (1989). An electrophysiological probe of incidental semantic association. *Journal of Cognitive Neuroscience*, 1, 38–49.
- Luck, S. J., Hillyard, S. A., Mangun, G. R., & Gazzaniga, M. S. (1989). Independent hemispheric attention systems mediate visual search in split-brain patients. *Nature*, 342, 543–545.
- Arthur, D., Hillyard, S. A., Flynn, E., & Schmidt, A. (1989). Neural mechanisms of selective auditory attention. In S. J. Williamson, M. Hoke, G. Stroink, & M. Kotani (Eds.), *Advances in biomagnetism* (pp. 113–116). New York: Plenum Press.
- Mangun, G. R., & Hillyard, S. A. (1990). Allocation of visual attention to spatial locations: Tradeoff functions for event-related brain potentials and detection performance. *Perception and Psychophysics*, 47, 532–550.
- Heinze, H. J., Luck, S. J., Mangun, G. R., & Hillyard, S. A. (1990). Visual event-related potentials index focussed attention with bilateral stimulus arrays. I: Evidence for early selection. *Electroencephalography and Clinical Neurophysiology*, 75, 511–527.
- Luck, S. J., Heinze, H. J., Mangun, G. R., & Hillyard, S. A. (1990). Visual event-related potentials index focussed attention within bilateral stimulus arrays. II: Functional dissociation of P1 and N1 components. *Electroencephalography and Clinical Neurophysiology*, 75, 528–542.
- Mangun, G. R., & Hillyard, S. A. (1990). Electrophysiological studies of visual selective attention in humans. In A. B. Scheibel & A. F. Wechsler (Eds.), *Neurobiology of higher cognitive function* (pp. 271–295). New York: Guilford Press.
- Hackley, S. A., Woldorff, M., & Hillyard, S. A. (1990). Cross-modal selective attention effects on retinal, myogenic, brainstem and cerebral evoked potentials. *Psychophysiology*, 27, 195–208.
- Hillyard, S. A., Mangun, G. R., Luck, S. J., & Heinze, H. J. (1990). Electrophysiology of visual attention. In E. R. John, T. Harmony, L. Prichep, M. Valdez, & P. Valdes (Eds.), *Machinery of the mind* (pp. 186–205). Boston: Birkhauser.
- Woldorff, M., & Hillyard, S. A. (1990). Attentional influence on the mismatch negativity. *Behavioral and Brain Sciences*, 13, 258–260.
- Kutas, M., Hillyard, S. A., Volpe, B. T., & Gazzaniga, M. S. (1990). Late positive event-related potentials after commissural section in humans. *Journal of Cognitive Neuroscience*, 2, 258–271.
- Luck, S. J., & Hillyard, S. A. (1990). Electrophysiological evidence for parallel and serial processing during visual search. *Perception and Psychophysics*, 48, 603–617.
- Hawkins, H. L., Hillyard, S. A., Luck, S. J., Mouloua, M., Downing, C. J., & Woodward, D. P. (1990). Visual attention modulates signal detectability. *Journal of Experimental Psychology: Human Perception and Performance*, 16, 802–811.
- Heinze, H. J., Mangun, G. R., & Hillyard, S. A. (1990). Visual event-related potentials index perceptual accuracy during spatial attention to bilateral stimuli. In C. Brunia et al. (Eds.), *Psychophysiological brain research* (pp. 196–202). Tilburg, The Netherlands: Tilburg University Press.
- Woldorff, M. G., Hackley, S. A., & Hillyard, S. A. (1991). The effects of channel-selective attention on the mismatch negativity wave elicited by deviant tones. *Psychophysiology*, 28, 30–42.
- Woldorff, M. G., & Hillyard, S. A. (1991). Modulation of early auditory processing during selective listening to rapidly presented tones. *Electroencephalography and Clinical Neurophysiology*, 79, 170–191.
- Mangun, G. R., & Hillyard, S. A. (1991). Modulation of sensory-evoked brain potentials provide evidence for changes in perceptual processing during visual-spatial priming. *Journal of Experimental Psychology: Human Perception and Performance*, 17, 1057–1074.
- Iragui, V. J., Kutas, M., Mitchiner, M. R., & Hillyard, S. A. (1993). Effects of aging on event-related brain potentials and reaction times in an auditory oddball task. *Psychophysiology*, 30, 10–22.
- Bentin, S., Kutas, M., & Hillyard, S. A. (1993). Electrophysiological evidence for task effects on semantic priming in auditory word processing. *Psychophysiology*, 30, 161–169.
- Luck, S. L., Fan, S., & Hillyard, S. A. (1993). Attention-related modulation of sensory evoked brain activity in a visual search task. *Journal of Cognitive Neuroscience*, 5, 188–195.
- Hillyard, S. A. (1993). Electrical and magnetic brain recordings: Contributions to cognitive neuroscience. *Current Opinion in Neurobiology*, 3, 217–224.
- Mangun, G. R., Hillyard, S. A., & Luck, S. J. (1993). Electrocortical substrates of visual selective attention. In D. E. Meyer & S. Kornblum (Eds.), *Attention and performance XIV: Synergies in experimental psy-*

- chology, artificial intelligence, and cognitive neuroscience (pp. 219–243). Cambridge, MA: MIT Press.
- Woldorff, M. G., Gallen, C. C., Hampson, S. A., Hillyard, S. A., Pantev, C., Sobel, D., & Bloom, F. E. (1993). Modulation of early sensory processing in human auditory cortex during auditory selective attention. *Proceedings of the National Academy of Sciences*, *90*, 8722–8726.
- Hillyard, S. A., Luck, S. J., & Mangun, G. R. (1994). The cuing of attention to visual field locations: Analysis with ERP recordings. In H. J. Heinze, T. F. Münte, & G. R. Mangun (Eds.), *Cognitive electrophysiology: Event-related brain potentials in basic and clinical research* (pp. 1–25). Boston: Birkhauser.
- Luck, S. J., Hillyard, S. A., Mangun, G. R., & Gazzaniga, M. S. (1994). Independent attentional scanning in the separated hemispheres of split-brain patients. *Journal of Cognitive Neuroscience*, *6*, 84–91.
- Kutas, M., Iragui, V., & Hillyard, S. A. (1994). Effects of aging on event-related brain potentials (ERPs) in a visual detection task. *Electroencephalography and Clinical Neurophysiology*, *92*, 126–139.
- Luck, S. J., & Hillyard, S. A. (1994). Electrophysiological correlates of feature analysis during visual search. *Psychophysiology*, *31*, 291–308.
- Heinze, H. J., Luck, S. J., Münte, T. F., Goes, A., Mangun, G. R., & Hillyard, S. A. (1994). Attention to adjacent and separate positions in space: An electrophysiological analysis. *Perception and Psychophysics*, *56*, 42–52.
- Luck, S. J., Hillyard, S. A., Mouloua, M., Woldorff, M. G., Clark, V. P., & Hawkins, H. L. (1994). Effects of spatial cuing on luminance detectability: Psychophysical and electrophysiological evidence for early selection. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 887–904.
- Mangun, G. R., Luck, S. J., Plager, R., Loftus, W., Hillyard, S. A., Handy, T., Clark, V., & Gazzaniga, M. S. (1994). Monitoring the visual world: Hemispheric asymmetries and subcortical processes in attention. *Journal of Cognitive Neuroscience*, *6*, 267–275.
- Gomez, C. M., Clark, V. P., Fan, S., Luck, S. J., & Hillyard, S. A. (1994). Sources of attention-sensitive visual event-related potentials. *Brain Topography*, *7*, 41–51.
- Luck, S. J., & Hillyard, S. A. (1994). Spatial filtering during visual search: Evidence from human electrophysiology. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 1000–1014.
- Heinze, H. J., Mangun, G. R., Burchert, W., Hinrichs, H., Scholz, M., Münte, T. F., Gos, A., Scherg, M., Johannes, S., Hundeshagen, H., Gazzaniga, M. S., & Hillyard, S. A. (1994). Combined spatial and temporal imaging of brain activity during visual selective attention in humans. *Nature*, *372*, 543–546.
- Pashler, H., Luck, S. J., Hillyard, S. A., Mangun, G. R., O'Brien, S., & Gazzaniga, M. S. (1994). Sequential operation of disconnected cerebral hemispheres in split-brain patients. *NeuroReport*, *5*, 2381–2384.
- Bentin, S., Kutas, M., & Hillyard, S. A. (1995). Semantic processing and memory for attended and unattended words in dichotic listening: Behavioral and electrophysiological evidence. *Journal of Experimental Psychology: Human Perception and Performance*, *21*, 54–67.
- Hillyard, S. A., Mangun, G. R., Woldorff, M. G., & Luck, S. J. (1995). Neural systems mediating selective attention. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences* (pp. 665–681). Cambridge, MA: MIT Press.
- Luck, S. J., & Hillyard, S. A. (1995). The role of attention in feature detection and conjunction discrimination: An electrophysiological analysis. *International Journal of Neurosciences*, *80*, 281–297.
- Clark, V. P., Fan, S., & Hillyard, S. A. (1995). Identification of early visual evoked potential generators by retinotopic and topographic analyses. *Human Brain Mapping*, *2*, 170–187.
- Mangun, G. R., & Hillyard, S. A. (1995). Attention: Mechanisms and models. In M. D. Rugg & M. G. H. Coles (Eds.), *Electrophysiology of mind—Event-related potentials and cognition* (pp. 40–85). New York: Oxford University Press.
- Anllo-Vento, L., & Hillyard, S. A. (1996). Selective attention to the color and direction of moving stimuli: Electrophysiological correlates of hierarchical feature selection. *Perception and Psychophysics*, *58*, 191–206, 1996.
- Hillyard, S. A., Anllo-Vento, L., Clark, V. P., Heinze, H. J., Luck, S. J., & Mangun, G. R. (1996). Neuroimaging approaches to the study of visual attention: A tutorial. In M. Coles, A. Kramer, & G. Logan (Eds.), *Converging operations in the study of visual selective attention* (pp. 107–138). Washington, DC: American Psychological Association.
- Morgan, S. T., Hansen, J. C., & Hillyard, S. A. (1996). Selective attention to stimulus location modulates the steady-state visual evoked potential. *Proceedings of the National Academy of Sciences*, *93*, 4770–4774.
- Luck, S. J., Hillyard, S. A., Mouloua, M., & Hawkins, H. L. (1996). Mechanisms of visual-spatial attention: Resource allocation or uncertainty reduction? *Journal of Experimental Psychology: Human Perception and Performance*, *22*, 725–737.
- Clark, V., & Hillyard, S. A. (1996). Spatial selective attention affects early extrastriate but not striate components of the visual evoked potential. *Journal of Cognitive Neuroscience*, *8*, 387–402.
- Muller, M. M., Teder, W., & Hillyard, S. A. (1997). Magnetoencephalographic recording of steady-state visual evoked cortical activity. *Brain Topography*, *9*, 163–168.
- Luck, S. J., Chelazzi, L., Hillyard, S. A., & Desimone, R. (1997). Neural mechanisms of spatial selective attention in areas V1, V2, and V4 of macaque visual cortex. *Journal of Neurophysiology*, *77*, 24–42.
- Hillyard, S. A. (1997). Commentary on Article by John, Easton and Isenhardt. *Consciousness and Cognition*, *6*, 50–55.
- Hillyard, S. A., Hinrichs, H., Tempelmann, C., Morgan, S. T., Hansen, J. C., Scheich, H., & Heinze, H. J. (1997). Combining steady-state visual evoked potentials and fMRI to localize brain activity during selective attention. *Human Brain Mapping*, *5*, 287–292.
- Hillyard, S. A., & Anllo-Vento, L. (1998). Event-related brain potentials in the study of visual selective attention. *Proceedings of the National Academy of Sciences*, *95*, 781–787.
- Hillyard, S. A., Teder-Sälejärvi, W. A., & Münte, T. F. (1998). Temporal dynamics of early perceptual processing. *Current Opinion in Neurobiology*, *8*, 202–210.
- Müller, M. M., Picton, T. W., Valdes-Sosa, P., Riera, J., Teder-Sälejärvi, W. A., & Hillyard, S. A. (1998). Effects of spatial selective attention on the steady-state visual evoked potential in the 20–28 Hz range. *Cognitive Brain Research*, *6*, 249–261.
- Hillyard, S. A., Vogel, E. K., & Luck, S. J. (1998). Sensory gain control (amplification) as a mechanism of selective attention: Electrophysiological and neuroimaging evidence. *Philosophical Transactions of the Royal Society: Biological Sciences*, *353*, 1257–1270.
- Anllo-Vento, L., Luck, S. J., & Hillyard, S. A. (1998). Spatio-temporal dynamics of attention to color: Evidence from human electrophysiology. *Human Brain Mapping*, *6*, 216–238.
- Woldorff, M. G., Hillyard, S. A., Gallen, C. C., Hampson, S. A., & Bloom, F. E. (1998). Magnetoencephalographic recordings demonstrate attentional modulation of mismatch-related neural activity in human auditory cortex. *Psychophysiology*, *35*, 283–292.
- Teder-Sälejärvi, W. A., & Hillyard, S. A. (1998). The gradient of spatial auditory attention in free-field: An event-related potential (ERP) study. *Perception and Psychophysics*, *60*, 1228–1242.
- Müller, M. M., Teder-Sälejärvi, W. A., & Hillyard, S. A. (1998). The time course of cortical facilitation during cued shifts of spatial attention. *Nature Neuroscience*, *1*, 631–634.
- Hillyard, S. A. (1999). Event-related potentials and human information processing. In G. Adelman & B. H. Smith (Eds.), *Encyclopedia of neuroscience* (2nd ed., pp. 679–682). Amsterdam: Elsevier.
- Martinez, A., Anllo-Vento, L., Sereno, M. I., Frank, L. R., Buxton, R. B., Dubowitz, D. J., Wong, E. C., Hinrichs, H., Heinze, H. J., & Hillyard, S. A. (1999). Involvement of striate and extrastriate visual cortical areas in spatial attention. *Nature Neuroscience*, *2*, 364–369.
- Hillyard, S. A. (1999). Electrophysiology, electric & magnetic fields. In R. A. Wilson & F. C. Keil (Eds.), *The M.I.T. encyclopedia of the cognitive sciences* (pp. 262–264). Cambridge, MA: MIT Press.
- Röder, B., Teder-Sälejärvi, W., Sterr, A., Rösler, F., Hillyard, S. A., & Neville, H. J. (1999). Improved auditory spatial tuning in blind humans. *Nature*, *400*, 162–166.
- Luck, S. J., & Hillyard, S. A. (2000). The operation of selective attention at multiple stages of processing: Evidence from human and monkey electrophysiology. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences* (2nd ed., pp. 687–700). Cambridge, MA: MIT Press.
- Picton, T. W., Bentin, S., Berg, P., Donchin, E., Hillyard, S. A., Johnson, Jr., R., Miller, G. A., Ritter, W., Ruchkin, D. S., Rugg, M. D., & Taylor, M. J. (2000). Guidelines for using human event-related potentials to study cognition: Recording standards and publication criteria. *Psychophysiology*, *37*, 1–26.
- Teder-Sälejärvi, W. A., Hillyard, S. A., Röder, B., & Neville, H. J. (1999). Spatial attention to central and peripheral auditory stimuli as indexed by event-related potentials (ERPs). *Cognitive Brain Research*, *8*, 213–227.
- Teder-Sälejärvi, W. A., Münte, T. F., Sperlich, F. -J., & Hillyard, S. A. (1999). Intra-modal and cross-modal spatial attention to auditory and visual stimuli: An event-related brain potential (ERP) study. *Cognitive Brain Research*, *8*, 327–343.