In Memoriam: Risto Näätänen (1939–2023)

Kimmo Alho,[1*] Carles Escera,[2,3,4] Teija Kujala,[1,5] Erich Schröger,[6] Mari Tervaniemi,[5,7] István Winkler,[8] and Hirooki Yabe[9]

[1]Department of Psychology and Logopedics, University of Helsinki, Helsinki, Finland
[2]Department of Clinical Psychology and Psychobiology, University of Barcelona, Barcelona, Catalonia-Spain
[3]Institute of Neurosciences, University of Barcelona, Barcelona, Catalonia-Spain
[4]Institut de Recerca Sant Joan de Déu (IRSJD), Esplugues de Llobregat, Barcelona, Catalonia-Spain
[5]Cognitive Brain Research Unit, University of Helsinki, Helsinki, Finland
[6] Wilhelm Wundt Institute for Psychology, Leipzig University, Leipzig, Germany
[7]Department of Education, University of Helsinki, Helsinki, Finland
[8]Institute of Cognitive Neuroscience and Psychology, HUN-REN Research Centre for Natural Sciences, Budapest, Hungary
[9]Department of Mind & Brain Medicine, Fukushima Medical University (FMU), Fukushima, Japan

*The authors are listed in alphabetical order

Risto Näätänen, a distinguished member of the Society for Psychophysiological Research (SPR), died peacefully of COVID-19 in the hospital in Helsinki, Finland, on October 5, 2023, at the age of 84 years. He received the SPR Distinguished Contributions Award in 1995 (Ritter, 1996) and served as the president of the SPR from 1998–1999. Over the years, he also served as the president of the Federation of European Psychophysiology Societies, the Nordic Psychophysiological Society, the Brain Research Society of Finland, and the Finnish Academy of Science and Letters. Moreover, he was an invited member of Academia Europaea and the International Academy of Science, Russian Academy of Sciences, and Royal Swedish Academy of Sciences, and a fellow of the Association for Psychological Science. He was also an honorary doctor of the University of Barcelona, University of Tartu, University of Jyväskylä, and University of Helsinki. In addition to the SPR Distinguished Contributions Award, he received many other awards, including the Alexander von Humboldt Research Fellowship Award in 1979, the first National Science Award of Finland in 1997, the Award for Highly Exceptional and Prize-Worthy Contributions to Psychophysiology and Related Neurosciences of the International Organization of Psychophysiology in 2002, the Nordic Prize for Research within Neurodevelopmental Disorders (together with Teija Kujala) in 2007, and the Main Scientific Prize of the Finnish Academy of Science and Letters in 2011.

Risto received his PhD degree from the University of Helsinki in 1968 and was appointed Professor of Psychology at the same university in 1975. In 1983, he was appointed Academy Professor, a five-year research professor position funded by the Research Council of Finland, and, exceptionally, he was re-appointed several times. He left this position in 2007 after reaching the maximum retirement age of 68. Thereafter, he continued his career as George Soros Professor of Psychology at the University of Tartu and Visiting Professor at the Centre of Functionally Integrative Neurosciences of the University of Aarhus. During his career, Risto supervised over 30 completed PhDs and over 20 post-doctoral researchers, including the present authors. His list of publications includes over 400 original and review articles, as well as several books he wrote either as the only author or together with colleagues. According to Google Scholar, to date, he has been cited over 80000 times and has an *h*-index of 144 (https://scholar.google.com/citations?user=5zWLGskAAAAJ&hl=fi&oi=sra).

In 1965–1966, Risto collected electroencephalogram (EEG) data for his PhD thesis (Näätänen, 1967) in Donald B. Lindsley's laboratory at the University of California Los Angeles. Several previous event-related potential (ERP) studies on selective attention had applied a paradigm where, for example, tone pips and light flashes were delivered in an alternating order with participants instructed to selectively attend to the stimuli of one modality and ignore the stimuli of the other modality. These studies had reported differences between ERPs to attended and unattended tones, as well as between attended and unattended flashes. In his thesis, Risto demonstrated that when such a predictable stimulus order was used, the ERPs to attended stimuli were overlapped by slow potential shifts and amplitude changes in EEG. These EEG effects were associated with anticipation of the attended stimulus and already began before its onset. Thus, the study showed that in this fixed-stimulus-order paradigm, the differences observed between ERPs to attended and unattended stimuli were due to anticipation rather than selective attention.

A few years later, Hillyard, Hink, Schwent, and Picton (1973) applied a paradigm where attended and unattended tones were delivered in an unpredictable order to the opposite ears. They observed that the negative-polarity N1 response peaking around 100 ms from tone onset was larger in ERPs to tones delivered to one ear when these tones were selectively attended to than when they were unattended to, that is, when attention was directed to tones delivered to the other ear). In 1975, this first reliable evidence for the effect of selective attention on human brain activity was also noted in Risto's meritorious review article (Näätänen, 1975). Around the same time, Risto and his doctoral student Sirkka Mäntysalo collected their own ERP data in collaboration with Tony Gaillard at the Institute for Perception TNO in Soesterberg, The Netherlands, since EEG facilities were not yet available at the University of Helsinki's Department of Psychology. Using a paradigm similar to that employed by Hillyard and colleagues (1978), except for a somewhat slower stimulus rate (1 tone per second) and longer time constant in EEG recordings, Risto and his team observed a negative displacement of ERP to attended tones in relation to the ERP to unattended tones, the displacement beginning at the N1 latency and continuing for hundreds of milliseconds (Näätänen, Gaillard, & Mäntysalo, 1978). They named this slow ERP effect the processing negativity (PN). Later studies demonstrated that unattended stimuli physically close to attended stimuli also elicit a shorter duration PN (for a review, see Näätänen, 1990). This supported Risto's theory that the selection of attended sounds for further processing, and the rejection of unattended sounds, is based on the comparison of each sound with an 'attentional trace,' a neural facilitation pattern

maintained in the auditory cortex and representing physical features of attended sounds, such as their location and pitch (Näätänen, 1982, 1990, 1992).

Like Hillyard and colleagues (1973), Risto's team (Näätänen et al., 1978) ensured participants' attention to tones delivered to the designated ear by instructing them to detect in that ear infrequent ('deviant') tones that were slightly higher in pitch than the frequent ('standard') tones delivered to the same ear. Such deviant tones also occurred among the standard tones delivered to the unattended ear. Risto and his team observed that in the ERPs to these to-be-ignored deviant tones, the N1 response was followed by another negative-polarity response, and they termed this the mismatch negativity (MMN). They suggested that the MMN is automatically elicited by sounds deviating from a sensory memory trace representing physical features of standard sounds and formed by these sounds, due to their repetition, even in the absence of attention. These hypotheses were supported by numerous subsequent studies (Näätänen, 1990; Näätänen, 1992; Näätänen & Winkler, 1999). Risto and his colleagues (1978) further suggested that in addition to auditory sensory memory, the process underlying the MMN response might be closely related to the orienting response. Indeed, subsequent studies confirmed the association between the MMN and the involuntary orienting of attention to changes in the auditory environment (Escera, Alho, Winkler, & Näätänen, 1998; Escera, Alho, Schröger, & Winkler, 2000; Näätänen et al., 2002). Theories of predictive processing (e.g., Friston, 2010) also found important support from the deviance detection function indexed by the MMN (Näätänen, Kujala, & Winkler, 2011b), and currently the MMN is typically interpreted as reflecting prediction error (e.g., Winkler & Schröger, 2015).

In the early 1980s, Risto began leading a psychophysiological research group at the Department of Psychology, University of Helsinki, with a focus on the brain mechanisms of auditory selective attention reflected by the PN and auditory sensory memory studied with the MMN. In the 1990s, this group expanded into the Cognitive Brain Research Unit, with wider research interests and additional brain research methods, including magnetoencephalography (MEG; e.g., Näätänen, Alho, & Ilmoniemi, 1994), transcranial magnetic stimulation (TMS; e.g., Ilmoniemi, Virtanen, Ruohonen, Karhu, Aronen, Näätänen et al., 1997), positron emission tomography (PET; e.g., Alho, Medvedev, Pakhomov, Roudas, Zeffiro et al., 1999; Tervaniemi, Medvedev, Alho, Pakhomov, Roudas et

al., 2000), and functional magnetic resonance imaging (fMRI; e.g., Schönwiesner, Novitski, Pakarinen, Carlson, Tervaniemi et al., 2006).

Risto's highly influential ERP work began with slowly paced sinusoidal tones, but he was open to new initiatives for developing auditory stimulation to resemble authentic everyday sound scenes—to the extent permitted by sound technology in those times. Pioneering findings obtained using speech, musical sounds, and melody-like patterns enabled him to elaborate a theory about learning and interaction between long-term and sensory memory. This branch of his work is best illustrated by studies on the interplay between a person's native language and phoneme-change evoked MMN (Näätänen, Lehtokoski, Lennes, Cheour, Huotilainen et al., 1997) and between a person's musical expertise and the processing of musical sounds as reflected by the MMN (e.g., Tervaniemi, Rytkönen, Schröger, Ilmoniemi, & Näätänen, 2001). These studies also formed the basis of an influential review and model of 'primitive intelligence' as reflected by the MMN (Näätänen, Tervaniemi, Sussman, Paavilainen, & Winkler, 2001). Moreover, Risto was among the first researchers in auditory cognitive neuroscience to respect the need for an ecological approach in our field (Tervaniemi, 2022).

Risto's investigations, together with those in other laboratories, have demonstrated the immense range of research areas in cognitive and clinical neuroscience to which the MMN can be applied. As it is elicited irrespective of the direction of the participant's attention, even the brain function of sleeping infants and comatose patients can be studied using the MMN (Näätänen, Kujala, & Light, 2019). Studies with the MMN—or the mismatch response (MMR; the infant counterpart of the MMN)—have shown, for example, that newborns possess core speech processing abilities, such as statistical learning and detecting rules from acoustically variable speech signals (Kujala, Partanen, Virtala, & Winkler Partanen, E., Virtala, P., & Winkler, 2023). Thus, even newborn babies exhibit a readiness to categorize sounds, find boundaries between words and learn them, and identify separate speech streams. Existing as early as the fetal stage (Huotilainen, Kujala, Hotakainen, Parkkonen, Taulu et al., 2005), the MMR is an attractive tool for monitoring children's early auditory and language development (Virtala, Putkinen, Kailaheimo-Lönnqvist, Thiede, Partanen et al., 2023) and learning (Partanen, Kujala, Näätänen, Liitola, Sambeth et al., 2013). This also enables the determination of atypical development in neurodevelopmental disorders, such as the autism

spectrum, developmental language disorders, and developmental dyslexia (for reviews, see Kujala, Lepistö, & Näätänen, 2013; Kujala & Leminen, 2017; Gu & Bi, 2020).

A major focus of Risto's intellectual journey was to benefit society through the results of his research. Thus, early on, he became interested in fostering the clinical applications of the MMN (Näätänen & Escera, 2000). These studies first concentrated on pediatric and neurodevelopmental disorders (e.g., Cheour, Haapanen, Hukki, Čeponienė, Kurjenluoma et al., 1997), the recovery of consciousness in comatose patients (Kane, Curry, Butler, & Cummins, 1993), neurology (e.g., Alzheimer's disease; Pekkonen, Jääskeläinen, Hietanen, Huotilainen, Näätänen et al., 1999), and psychiatry (e.g., alcoholism and schizophrenia; Polo, Escera, Gual, & Grau, 1999; Shelley, Ward, Catts, Michie, Andrews et al., 1991). Later, the field experienced a major breakthrough regarding schizophrenia. Risto was convinced of the role of the MMN as a promising biomarker of the condition (Näätänen, Kujala, Escera, Baldeweg, Kreegipuu et al., 2012; Näätänen, Shiga, Asano, & Yabe, 2015), since it is already attenuated in the early stages of the disease (Todd, Michie, Schall, Karayanidis, Yabe et al., 2008), longitudinal Heschl's gyrus reduction in schizophrenia is highly correlated with MMN reduction (Salisbury, Kuroki, Kasa, Shenton, & McCarley, 2007), and cognitive impairment in schizophrenia is underpinned by the dysfunction of the glutamate N-methyl-D-aspartate (NMDA) receptor system underlying MMN generation (Javitt, 2000). In later years, Risto also focused on using the MMN to predict psychosis in clinically at-risk-mental-state individuals by recording the MMN based on deviation in sound duration (Näätänen et al., 2015).

Advances in the clinical applications of the MMN were reviewed in a comprehensive article published in 2012 (Näätänen et al., 2012). Risto's inquisitive mind drove him to seek an explanation for the significance of the MMN in such a diverse set of clinical conditions. He related these findings to the potential neurophysiological (synaptic) mechanisms underlying the generation of the MMN, suggesting that the common dysfunction that can be detected with the MMN reflects a more widespread brain disorder, namely, a deficient NMDA receptor function, common to all these clinical conditions and accounting for most of the cognitive decline in them (Näätänen, Kujala, Kreegippu, Carlson, Escera et al., 2011a).

Four decades of research on the MMN are summarized in a book by Risto and colleagues titled 'The mismatch negativity (MMN): A window to the brain' (Näätänen et al., 2019). The

book reviews MMN studies contributing to cognitive neuroscience as well as the applications of the MMN in developmental and clinical neuroscience. The book was released on Risto's 80th birthday, and his happiness and satisfaction with the completion of this important and final piece of scientific work was evident to everyone at his birthday celebration.

This memorial would be incomplete without mentioning Risto's activity in the field of traffic psychology. In the early 1970s, Risto took this 'side path' in his career, as he called it, due to the lack of experimental EEG facilities in Helsinki and the high number of traffic-accident casualties in Finland. At this time, there were no speed limits on Finnish highways, and governmental committees had concluded that setting speed limits would not reduce the number of accidents. Risto reviewed the committee reports and relevant studies, found errors in the interpretation of the data and the conclusions of the reports, and wrote a book (in Finnish) about his findings titled 'Maantiekuolema: Tutkimus liikenneonnettomuuksista' ('Death on the road: A study on traffic accidents'; Näätänen, 1972). In this book, he also developed a theory of risk-taking behavior. Risto sent a copy of the book to the President of Finland, who cited it in his next New Year's speech, which resulted in government officials changing their minds and, finally, establishing permanent speed limits on all roads in Finland. In collaboration with Heikki Summala (now Professor Emeritus of Traffic Psychology), Risto published a wider book on traffic safety and behavior titled 'Road-user behavior and traffic accidents' (Näätänen & Summala, 1976), as well as several articles on this topic (e.g., Näätänen & Summala, 1974).

Risto was an impressive person in many respects. When meeting him, he was extremely attentive and engaging. He was a good listener and able to convey his message pleasantly and concisely in just a few sentences. Although he sometimes appeared a little shy, he possessed an incredibly subtle, quiet sense of humor that was hard to resist. His discreet manner made him very appealing to other people. Hence, he developed an enormous network of colleagues all over the world. His personal relationships were academic and friendly. With his persuasive, always pleasant manner, the scientific 'mismatch negativity community' developed into a 'mismatch negativity family'.

Risto was a friend of science, and in scientific discourse he debated consistently but fairly. He was also incredibly focused and effective. If you met him at the airport on the way to or from a scientific conference, he was always engrossed in reading, revising, and commenting

on some manuscript. Risto took great care of the next generation of scientists. His numerous, (mostly) constructive comments on the manuscript drafts of his colleagues were legendary. One of the present authors remembers a handwritten comment in the margin of the approximately 25th version of a manuscript: "Kimmo, you should think when you write!" Risto taught many young scientists how to write scientifically and made it a prerequisite for obtaining a doctorate: "A PhD must be able to write!" One reason for the high number of citations of Risto's scientific work is probably his attempt to write unambiguous scientific text with no room for misinterpretation by the reader. He also taught his students, post-docs, and colleagues to avoid a high-flown, descriptive writing style and to be as simple and concrete as possible. The result may be slightly boring linguistically, but it is scientifically exact.

Risto is deeply missed by his wife Marjatta, to whom he was married for over 63 years, and their three sons, daughter-in-law, and grandchildren. He is also missed by his friends, students, and colleagues. Risto is not with us anymore, but his legacy remains, and his scientific influence continues in the work of his students and colleagues and in the work of their students and colleagues.

ORCID

Kimmo Alho https://orcid.org/0000-0001-8563-2792
Carles Escera https://orcid.org/0000-0001-8203-2951
Teija Kujala https://orcid.org/0000-0002-8814-605X
Erich Schröger https://orcid.org/0000-0002-8321-6629
Mari Tervaniemi https://orcid.org/0000-0002-9651-2929
István Winkler https://orcid.org/0000-0002-3344-6151
Hirooki Yabe https://orcid.org/0000-0003-2668-129X

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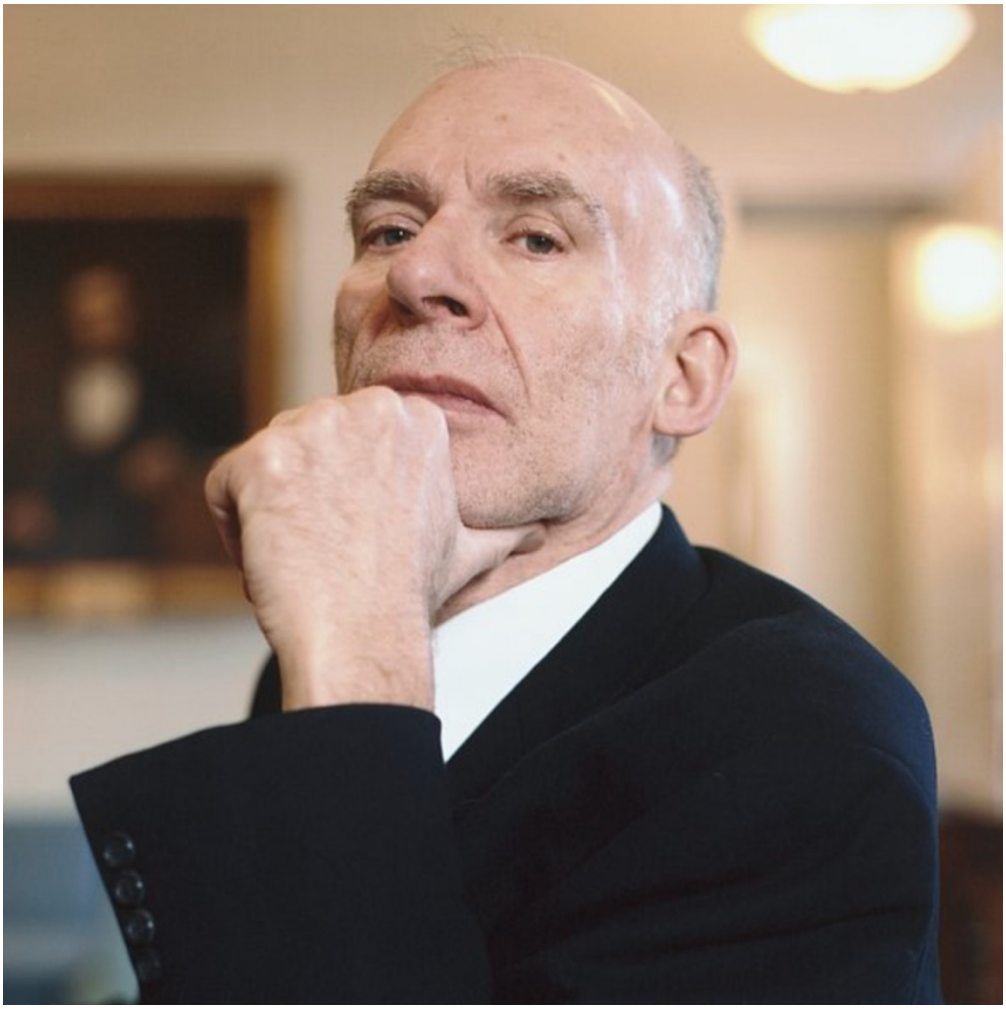

660x660mm (72 x 72 DPI)