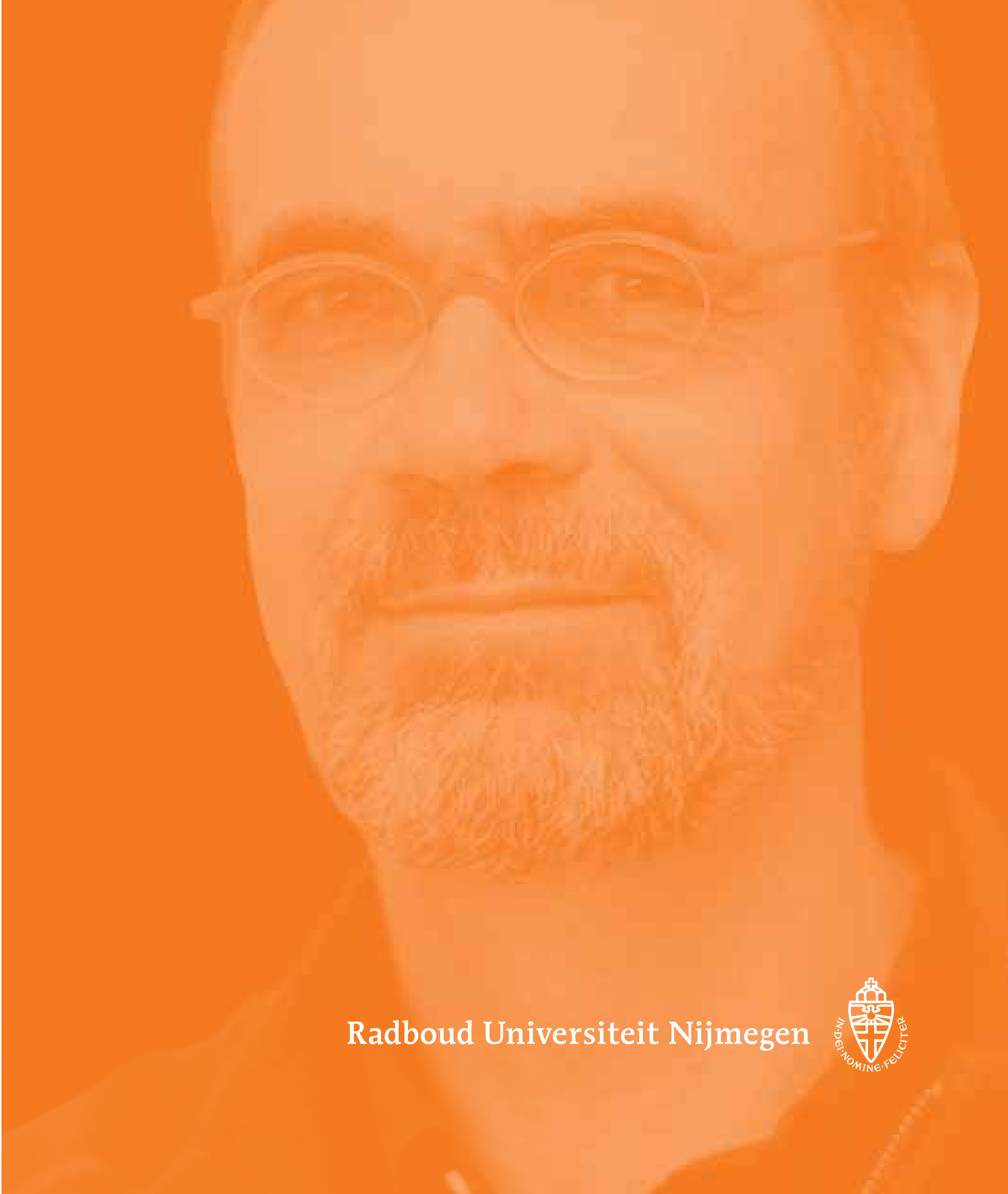
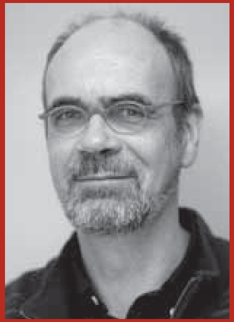
Cognitive neuroscience on the move

INTREEREDE DOOR PROF. DR. R. MEULENBROEK



Radboud Universiteit Nijmegen

INTREEREDE PROF. DR. RUUD MEULENBROEK



Ruud Meulenbroek pleit in zijn intreerede als hoogleraar Motorische Controle, in het bijzonder van Doelgericht Handelen, voor multidisciplinair onderwijs en onderzoek op het gebied van de cognitieve neurowetenschap. Met geavanceerde beeldvormingstechnieken onderzoekt deze discipline processen in de hersenen van de mens terwijl deze complexe taken uitvoert en zij creëert daarmee nieuwe inzichten in de relaties tussen hersenen, cognitie en gedrag. Het nog jonge vakgebied vergt samenwerkingsverbanden die traditionele disciplinegrenzen overstijgen. Meulenbroek geeft uit zijn eigen onderzoekscarrière een aantal voorbeelden van dergelijke verbanden.

Dr. R.G.J. (Ruud) Meulenbroek (1958, Middelburg) is sinds 1 september 2007 hoogleraar bij de Faculteit der Sociale Wetenschappen van de Radboud Universiteit Nijmegen met als leeropdracht Motorische Controle, in het bijzonder van Doelgericht Handelen. Hij studeerde psychologie aan de Universiteit van Tilburg en de Radboud Universiteit Nijmegen en promoveerde in 1989 op de dissertatie ‘A study of handwriting production: Educational and developmental aspects’. Sinds 1984 is hij werkzaam aan de Radboud Universiteit bij de groep Cognitieve Psychologie, ondergebracht in het ‘Nijmegen Institute for Cognition and Information’ (NICI). Meulenbroek is deskundig op het gebied van de motorische controle, met name de neurocognitieve achtergronden van de planning, uitvoering en coördinatie van bewegingen. Sinds 2004 geeft hij leiding aan het Europese onderzoeksproject ‘Joint Action Science and Technology’. Sinds 2006 is hij opleidingsdirecteur van het tweejarige Master of Science-programma ‘Cognitive Neuroscience’ aan de Radboud Universiteit Nijmegen.

Radboud Universiteit Nijmegen

COGNITIVE NEUROSCIENCE ON THE MOVE

‘Cognitive neuroscience on the move’

Rede uitgesproken bij de aanvaarding van het ambt van hoogleraar Motorische Controle, in het bijzonder van Doelgericht Handelen aan de Faculteit der Sociale Wetenschappen van de Radboud Universiteit Nijmegen op donderdag 17 april 2008

door prof. dr. Ruud Meulenbroek

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Mijnheer de rector, dames en heren,

Vanwege de aanwezigheid van enkele buitenlandse gasten en omdat ik met een deel van de aanwezige collega's en studenten dagelijks in het Engels communiceer, zal ik deze lezing in het Engels geven.

As a multidisciplinary science, Cognitive Neuroscience is on the move. Thanks to the development of new imaging techniques that allow scientists to track the oxygen consumption in the brain of subjects who are performing experimental tasks, research into the neural correlates of cognitive functions has been given a tremendous impetus. With the spatially accurate fMRI technique and temporally accurate EEG method, cognitive neuroscientists now have powerful methodologies at their disposal to find answers to new research questions. With the addition of Transcranial Magnetic Stimulation (TMS), the research is moving from the level of correlational to the level of causal relationships. Cognitive neuroscience tries to unravel the neuroanatomical, neurophysiological and neurocomputational mechanisms responsible for cognitive functions such as perception, memory, language and action. To accurately interpret the data obtained in this domain, sound theoretical models of the cognitive functions under study are indispensable. Furthermore, the research in this discipline also frequently involves neurodegenerative, neuropsychological or psychiatric disorders, which makes the domain clinically relevant as well.

Fig. 1. Logo van het CNS 'Student Journal'

The Radboud University has recognised the importance of this development. In 2002 the FC Donders Centre for Cognitive Neuroimaging was established on our campus. A year later, a two-year 'Master of Science' (MSc) programme in Cognitive Neuroscience, or CNS masters, was launched, a programme in which about 60 lecturers of five faculties and three research institutes strive to prepare a selected group of ambitious students for a career in science. It is an honour to be the director of such a prestigious programme that each year attracts roughly 25 students with a Bachelor's degree in behavioural science, linguistics, biology, biophysics or the medical sciences. About half of the CNS students that enroll in the programme obtained their bachelor degree at our university, a quarter did so at another Dutch university, and another 25% stem from foreign universities. Those students that meet the stringent selection criteria of the programme tend to belong to the top 5% of their cohort. Nevertheless, at the beginning of the programme I warn them that they, by definition, have deficiencies in their academic training so far, the reason being that their schooling was monodisciplinary whereas the CNS programme is a multidisciplinary curriculum. The programme therefore not only requires excellent achievements in a cognitive-neuroscience domain-relevant bachelor's degree but also an academic attitude that is characterised by curiosity, endurance and modesty. As future scientists, besides being curious and persistent, having to clear many hurdles, cns students need to be modest and respectful to disciplines other than their own.

At the start of a challenging two-year master's programme my warning may seem demotivating to enthousiastic students but I am convinced it makes sense. Moreover, I think that the lecturers contributing to the programme, as well as university management, also need to embrace these preconditions for multidisciplinarity; if they don't, the endeavour is bound to fail. To support these claims I would like to take a detour in this lecture and discuss some studies in a research area that is most familiar to me: the study of human motor control. With this detour, I intend to show how these studies relate to cognitive neuroscience and to demonstrate the extent to which they profited from multidisciplinary collaboration.

MOTOR CONTROL

Human motor control is a research domain in which many disciplines play a part. Besides biophysics, neurophsyiology and biology, cognitive psychology has a prominent role in analysing the information processes that are necessary for goal-directed task performance. But what is goal-directed task performance? To mention just a few examples, maintaining your balance during stance and gait, exploring the environment by means of targeted eye, head and trunk movements, reaching, obstacle avoidance, grasping, object manipulation, speaking, typing, sports, playing music, handling a mobile phone, all forms of movement generation of which we readily recognise the behavioural goals. However, which cognitive processes underlie our ability to produce these forms of behaviour, is a question that is seldom asked. A neurocognitive scientist intrigued by the fundamentals of human action, perception and consciousness does pose that question. What processes occur during the preparation of movements? Which take place when people generate movements? And which are responsible for the evaluation of the results of goal-directed movements? We know that most of these processes are not directly observable and have to be inferred from clever experimentation. And what about cognition? How substantial is its role in human motor control? It has been suggested that its contributions are minimal. Should we indeed consider movements as mere reflexes that, through learning, have become more articulated? Or should they rather be seen as directly linked to perceptual invariants that, by association, elicit a fixed behavioural response from an in-built action repertoire? Or, as a third model posits, can movements be best explained by their intrinsic dynamic features? In my view, these non-cognitive accounts of motor control, even though valuable and important to take into consideration, are insufficient explanations of goal-directed human action. Although a large part of the control processes seemingly require little or no conscious attention and thus seem to be automatic and effortless, skilled motor performance is always under cognitive control. Within the framework of this latter viewpoint, I have been involved in a series of experiments examining goal-directed arm, hand and finger movements, each study addressing a different question. A graphic overview of some of these studies is shown in Figure 2. I will now turn to some examples and highlight how the studies relate to the domain of cognitive neuroscience.

Fig. 2. Examples of goal-directed movements studied.

INFORMATION PROCESSES

Fig. 3. F.C. Donders (1818-1889)

In the 1980s the search for independent information processing stages underlying complex task performance was very much in vogue in experimental psychology. Retrieving abstract movement representations from long-term motor memory, specifying the free parameters of these representations in a short-term motor buffer, and activating the relevant muscle groups that, when contracted, bring about the intended movements, are examples of such processes (see e.g. Sanders, 1983). Franciscus Donders, born in Tilburg (the Netherlands) in 1818, demonstrated that the duration of such stages could be estimated by subtracting the latency needed to initiate a simple movement from the latency required to start a more complex motor task. Saul Sternberg (1969) refined this subtraction method such that both the duration and independence of the inferred information processes could be determined. One of my first studies in experimental psychology, conducted with Gerard van Galen (Meulenbroek & Van Galen, 1983), exploited Sternberg's additive-factor method. We asked the participants to perform a choice-reaction time task in which, following the presentation of a visual cue, they had to write the cursive letter 'g' either forwards or backwards. In addition, the letter was to be produced either small or large, and finally, either in a forward or backward slanted version. The latter manipulation forced the participants to contract their wrist muscles when writing the first submovement of the allograph 'g' or their finger-thumb muscles, respectively. The effects of the three task variables on the choice reaction times were, as we expected, additive, which confirmed our model that claimed that programming, parameterisation and initiation were to be seen as subcomponents of movement preparation (Fig. 4). For cognitive neuroscience such a differentiation of processes is crucial because it can guide the search for the brain structures responsible for these processes. For instance, it allows hypotheses that programming corresponds with frontal brain activity, parameterisation with basal ganglia activity and initiation with activity in the parietal-prefrontal circuitry to be tested.

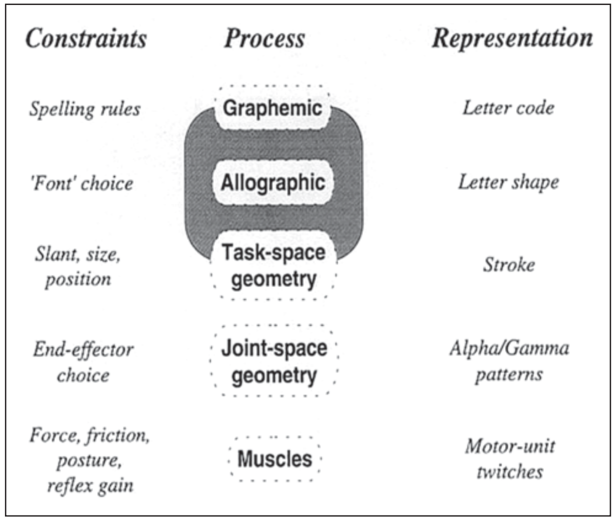

Fig. 4. Model of cursive handwriting (see Schomaker and Van Galen, 1996).

MOVEMENT DIRECTIONS

In the search for a principle that simplifies the control over the large number of muscles that contribute to graphic movements, the separate contractions of wrist and finger-thumb muscles during manipulations of a writing tool had been recognised earlier. I refer to the 1979 cybernetic model of cursive handwriting movements by Vredenbregt and Koster and Hollerbach's 1981 oscillation theory of handwriting (Fig. 5). Ar Thomassen and I later showed that in a free line-drawing task the principle yields preferences for anatomically simple movement directions, that is, directions that either require wrist rotations or finger-thumb excursions (Meulenbroek & Thomassen, 1991). In the horizontal, graphic plane these joint rotations correspond to diagonal movement directions (see Fig. 5). We additionally demonstrated that participants also display a strong preference for horizontal and vertical movements, the perceptually salient axes in such drawing tasks. As to their link with observations in cognitive neuroscience, these findings on movement-direction preferences correspond to the claim that some areas of the brain code information in allocentric spatial codes, like the premotor cortex, and other regions primarily process information in egocentric codes, like the parietal cortex. Thus, behavioural studies into the determinants of directional preferences are closely linked to studies in cognitive neuroscience that address coding in multiple coordinate systems.

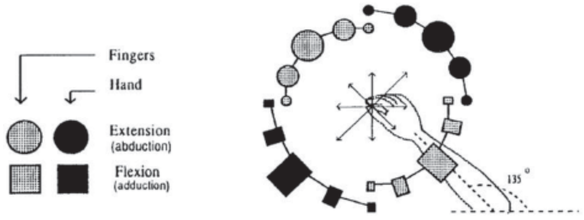

Fig. 5. Simplified model of directional preferences in free line-drawing (Meulenbroek & Thomassen, 1991)

MUSCLE STRESS

That a combination of orthogonally oriented oscillators can describe the curvilinear movements that occur in handwriting, was a powerful new insight. However, the description was limited to the low-frequency oscillations of handwriting movements while high-frequency components are also crucial in motor control. This becomes painfully clear when we consider the symptoms of neurodegenerative disorders like Parkinson's and Huntington's disease and multiple sclerosis. It is a well-known phenomenon that fatigue, task demands and stress tend to exacerbate muscle stiffness and tremors in patients. That the same factors may have similar, but, of course, much smaller effects on the high-frequency oscillations in the movements executed by healthy control subjects, is less well known. The insight that people adaptively exploit biomechanical and cognitive control mechanisms to avoid the loss of control that is associated with high-frequency oscillations due to increased muscle stiffness during movement production, is likewise hardly acknowledged. Among others, Gerard van Galen, Majken Hulstijn, Gijs Bloemsaat, Wouter Hulstijn and I have investigated this clinically relevant topic. The aim of our endeavours was to better understand Repetitive Strain Injury, a disability resulting from excessive use of the arm-hand-finger system in high-precision tasks, eventually leading to severe, debilitating pains in wrist, arm and neck. In one of our more recent studies (Meulenbroek et al., 2005) we asked participants to write a complex letter pair (such as nn, nm, mm or mn; Fig. 6) after they had been drawing ellipses for 6 seconds. Through headphones we concurrently presented the participants with an annoying sound while recording the surface-EMG of six forearm muscles as well as the speed of their movements. We concluded that muscular co-contraction was exploited to minimise the adverse effects stressors had on movement production. How neurobiological mechanisms manage to contain these high-frequency movement components is, however, still not well understood. Hopefully, our views and claims on this matter may guide future fMRI studies into the neural correlates of RSI.

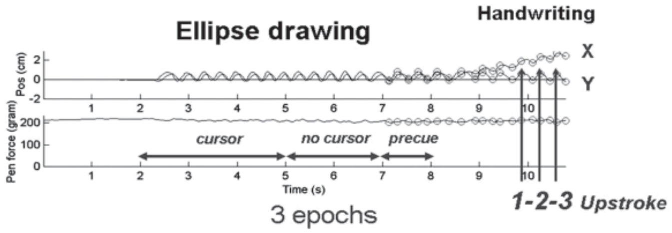

Fig. 6. Sample of handwriting data as obtained in Meulenbroek et al. (2005). The EMG data analysed in this study are not shown.

MOTION PLANNING

Our studies into the cognitive basis of directional preferences in free-line drawing tasks and into the modulation of co-contraction in response to increasing task demands demonstrated that biomechanical and cognitive factors jointly determine how people control the degrees of freedom available to them during the production of movements (Bernstein, 1968). This knowledge formed the basis of a longlasting collaboration with David Rosenbaum from Pennsylvania State University (USA) and Jonathan Vaughan from Hamilton College (USA) in which we developed a computational theory of motion planning. We based our theory on the assumption that goal-directed movements are prepared first by selecting a goal posture best suited to complete the task, and then by planning a movement towards that particular goal posture (Rosenbaum, Meulenbroek, Vaughan, & Jansen, 2001). Both planning processes are, according to our theory, embedded within a hierarchical representation of task goals. Accordingly, typical goals of a prehension task are: trying to grasp an object accurately, containing the effort that is put into the prehension movement, and avoiding colliding with obstacles that occur along the way (Fig. 7).

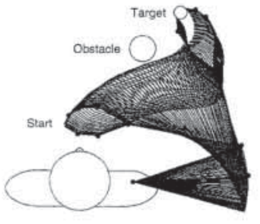

Fig. 7. Simulation of grasping movement and abstacle avoidance (Rosenbaum et al., 2001).

The prioritised goal list serves as a reference frame for the planning process. Success or failure subsequently determines whether in a next motion attempt less or more time needs to be reserved for planning. Our model of motion planning found support in the animal studies of Graziano (2002), which showed that, independent from the starting posture of a monkey's arm, 500 ms of electrical stimulation of regions in the premotor cortex elicited lifelike arm movements towards an invariant goal posture. In his publications Graziano makes use of the concept of 'goal-posture neurons', which demonstrates a remarkable convergence of insights obtained in neurophysiological research and our cognitive, computational theory of motion planning.

JOINT COORDINATION

The posture-based motion planning theory prompted a great deal of new research, not only in our own departments but also in other institutes where fundamental and applied motor control were being investigated. Some of our studies were aimed at evaluating key claims of our theory, others were directed at testing whether our theory could also be applied to tasks other than the ones that we had used to develop the theory. Of both types of research I would like to mention an example. In 1996 we applied our theory to cursive handwriting (Meulenbroek et al., 1996). By assuming that, in essence, handwriting consists of co-articulated series of small reaching movements, we not only succeeded in simulating handwriting movements in a lifelike manner, we were also able to account for a core phenomenon in motor control, namely motor equivalence. The phenomenon entails that, when given a goal for a particular movement pattern, people can use multiple means to reach that goal (Bernstein, 1967; Fig. 8). Humans are, for instance, similarly capable of writing their signature with a ballpoint pen on a piece of paper and, on a much larger scale, on the beach, in the sand using a foot. The ability to create spatially similar output demonstrates that in both these cases muscle-independent representations must underly the planning of the various movements. The motor-equivalence phenomenon is addressed in many neurocognitive studies that focus on the control of arm movements. They support the claim that in the frontal cortex key planning processes take place in an allocentric, muscle-independent frame of reference. The second example in which we put the generality of our model to the test involved the production of music.

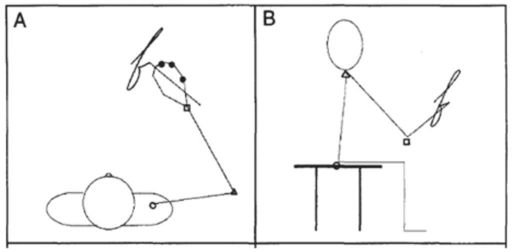

Fig. 8.A. The cursive letter *f* generated with simulated arm-, hand- and finger movements. B. The letter *f* simulated via hip-, shoulder- and elbow movements (Meulenbroek et al., 1996).

FINGER POSITIONING

Fig. 9. Set-up to test theory of Rosenbaum et al. in guitar playing (heijink & Meulenbroek, 2002).

We addressed the motor-equivalence phenomenon as it occurs in guitar playing. Several different positions on the neck of the guitar can lead to identical tones. This implies that, given a certain musical score, a guitar player needs to choose how and where to produce the desired tones on the guitar neck. In 2002, Hank Heijink and I showed that the optimalisation principles as formulated in our posture-based motion planning theory also applied to a musical context (Heijink & Meulenbroek, 2002; Fig. 9). Apart from musical goals, biomechanical efficiency principles co-determined the spatiotemporal features of the finger displacements of expert guitar players, which we regarded as a corroboration of our motion planning theory. How intricate the motion planning process is, was demonstrated by others in imaging studies that revealed that different brain structures become activated for the same finger movement sequence depending on the way they are educed, for instance when they are generated while the player is reading a musical score, or when his performance is the result of a creative improvisation process in the absence of external cues, or when he is merely imagining the sequence without actually producing it. Now that cognitive views on planning can be corroborated or challenged by neuroscientific observations, cognitive neuroscientific research is confronted with new challenges to try and specify the underlying mechanisms, topography and structure of movement representations in more detail (De Lange, Hagoort & Toni, 2006).

PARAMETER SETTING

A central claim of the posture-based motion planning theory that we have recently put to the test concerns goal prioritisation. The claim states that motion planning is embedded within a prioritised list of task constraints that need to be satisficed. If the list is long or complicated, people will take ample time to prepare their movements but if the list is short and straightforward, motion planning will not take them much time. For cyclical movements that require people to attend to two movement goals simultaneously, prioritised task-constraint satisfaction implies that they will try to find clever ways of bypassing their limited capacity to comply with these concurrent goals. One way is by exploiting biomechanics. Normally, an increase in movement amplitude coincides with a decrease in movement frequency and a decrease in amplitude with a frequency increment. In one of our experiments we asked participants to perform a loop-writing task in which, per trial, the frequency and amplitude of the target movements were imposed. We carefully analysed from one movement to the next the errors the participants generated and the extent to which the errors changed as a function of time (Fig. 10). This revealed that specifically under high speeds people cleverly exploit the biomechanical inverse relationship between movement amplitude and frequency (Bosga, Meulenbroek & Rosenbaum, 2005). How complex movements are generated, monitored and adjusted is one of the core topics in today's cognitive neuroscience and our paradigm may, in principle, contribute to this type of research in which time-series analyses have not yet been exploited to the full (De Bruijn, Sabbe & Hulstijn, 2006).

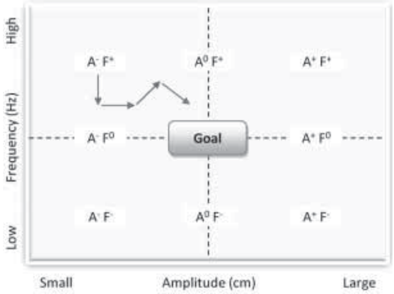

Fig. 10. Amplitude-frequency changes towards a goal parameter combination (Bosa, Meulenbroek & Rosenbaum, 2005).

COLLABORATIVE MOTOR CONTROL

Most studies into how people coordinate joint movements have, to date, focused on the tacit entrainment or mimicking of rhythmic motion patterns in tasks that lack any shared action goal (see e.g. Schmidt & O'Brien, 1997; Richardson et al., 2006). When speaking, for instance, people tend to adopt each other's speech rhythm. In our European research project 'Joint Action Science and Technology' (JAST) Jurjen Bosga and I have recently explored collaborative motor control when two people have to perform a goal-directed cyclical motor task together. In particular, we asked participants to jointly generate sideward movements of a particular amplitude and frequency while balancing on a rocking board (Bosga & Meulenbroek, 2007). The task is a typical exercise that is applied in physiotherapeutic settings to retrain people's sense of movement coordination. Using the same paradigm we employed in our parameter-setting experiments, we could show that also dyads cleverly exploit biomechanics in order to leave sufficient room to cognitively monitor both one's own actions and those of the co-actor while trying to anticipate each others' errors. The study is part of a larger research project that aims at capturing the neurocognitive basis of joint perception, reasoning and action in collaborative task performance. The neurocognitive processes of joint action studied in this project are summarised in Figure 11.

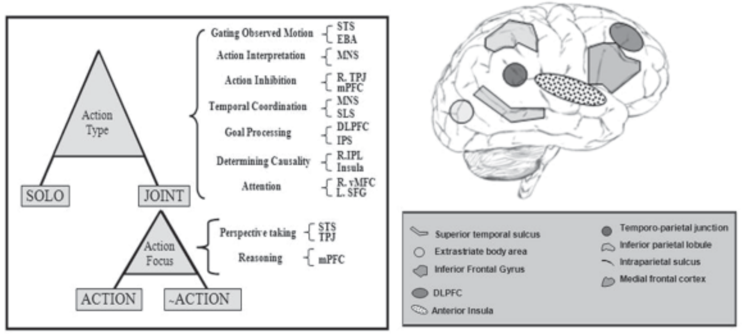

Fig. 11. Neurocognitive model of joint action (Newman-Norlund et al., 2007).

MULTIDISCIPLINARITY

At the start of my lecture I emphasised that neurocognitive research needs functional models of cognitive processes involved in perception and memory, and the perception and production of language and action. Researchers need such models as they provide a reference framework which enables them to draw inferences from the data they obtain in their investigations, whether these exploit behavioural, fMRI, EEG, MEG or TMS techniques. By describing some of the motor control studies I have been involved in since the 1980s, I hope I have demonstrated that cognitive scientists can provide such models. It is their refined views on the information processes that are assumed to underlie cognitive functions that yield testable hypotheses about brain regions taken to subserve these functions. The models that I have discussed provide workable hypotheses. It is clear that building comprehensive neurocognitive models relies on the insights and input of many. Luckily, in my endeavours I have not only been able to draw on many fellow cognitive psychologists but also on physiologists, biophysicists, information technologists and engineers; specialists in applied sciences like developmental psychology and physiotherapy have likewise contributed much to the work. All showed the exact combination of curiosity, endurance and modesty that I have mentioned as prerequisites of multidisciplinarity. Research can only become truly multidisciplinary if, for example, the biophysicist does not strictly adhere to physical laws alone but gives room to the experimental psychologist to formulate hypotheses about the cognitive control of movements, and, if the cognitive psychologist, in turn, recognises the extent to which movements are determined by biophysical principles.

INTERFACULTY CURRICULA

From the above it will have become clear that I fervently support multidisciplinarity in science and, rather than remaining the exception to the rule, it should be acknowledged as one of the most powerful means to move cognitive neuroscience forwards. I feel that both our academic curricula and infrastructures should reflect this notion more than they have done to date. Simply allocating university funds, and especially those aimed at promoting multidisciplinary programmes, across faculties without specifying shared responsibilities, is, in my view, wholly misguided. If experts in cognitive neuroscience are to teach the future generations of researchers in their multidisciplinary domain, their efforts should be fully recognised and compensated. If the two-year research master's programmes are to truly add to our universities' regular bachelor-master curricula, they deserve the full support of all parties involved (Koninklijke Nederlandse Akademie van Wetenschappen, 2008). As the director of the Radboud University's ambitious Cognitive Neuroscience Master's programme, but even more so as an enthusiastic researcher advocating multidisciplinary collaboration, I urge the management of all faculties that participate in the CNS programme to take up their responsibility and follow the example set by the Faculty of Social Sciences by recognising and committing to the programme and to accordingly provide the necessary didactical and financial support.

SIGNIFICANT OTHERS

And now I would like to turn to the acknowledgements. I will try to be as accurate as possible in mentioning all that have contributed to my career, but if I leave someone out, this is due to my already slightly failing memory functions rather than to any other reason. First of all, I thank the University Board for putting their trust in me to direct the most ambitious two-year research-master programme of this university. For my academic career I am indebted to Pieter Kop, Gerard van Galen, Arnold Thomassen, Wouter Hulstijn, David Rosenbaum and Jonathan Vaughan, all highly motivated scientists who have inspired me in my studies of the cognitive basis of human motor control. To start with, Pieter, who, back in Tilburg, first noticed my multidisciplinary mindset and motivated me to become a scientist. Then in Nijmegen Ar took over and I very much appreciated your belief in me and your support in providing me a tenure track. Gerard, you were not only an excellent PhD supervisor to me but also a wonderful colleague. I'd like to extend a special warm thanks to David Rosenbaum. Ever since your sabbatical stay in the Motor Control Nucleus at the NIAS in Wassenaar in 1998, we have entertained an inspiring professional and also close personal relationship, which I cherish both. I am also grateful to the longlasting collaborations with Stefan Swinnen of the Catholic University Leuven, Belgium, and Annie Vinter of the University of Dijon, France. Doing research together and encouraging each others' PhD students has been very rewarding. Since 1984 I have greatly enjoyed working with my NICI colleagues from the 'Action, Intention and Motor Control' group: Harold Bekkering, Pieter Medendorp, Ardi Roelofs, Ivan Toni and Bert Steenbergen. I appreciate the instrumental role that Charles de Weert and later Herbert Schriefers have played in supporting my position. Herbert, you stood at the cradle of the CNS masters, which I now proudly represent.

An academic career is impossible without the help of students, interns, junior and postdoc researchers. That's why I like to mention all the PhD students I have had the pleasure working with: Joost Schillings, Edwin van Thiel, Mary Klein Breteler, Hank Heijink, Gijs Bloemsaat, Paul Lemmens, Janneke Lommertzen and Jurjen Bosga. Although not always easy, we never failed to reach consensus and our joint efforts have been truly worthwhile. The 'NWO-MAGW'-funded research programme on human object manipulation from a perception-action perspective that I coordinated and participated in together with Stan Gielen, Geert Savelsbergh, Astrid Kappers and Hanneke van Mier proved an important step towards large-scale multidisciplinary research. Particularly inspiring has been the NICI JAST team that Harold Bekkering and I have been managing since October 2004. This European project relies heavily on Ellen de Bruijn, Majken Hulstijn, Raymond Cuijpers, Hein van Schie, Roger and Sarah Newman-Norlund, Jurjen Bosga as well as many research assistants. The JAST colleagues at the Max Planck Institute for Psycholinguistics and the FC Donders Centre for Cognitive Neuroimaging, Jan-Peter de Ruiter, Ivan Toni and Matthijs Noordzij are also respected contributors to this comprehensive venture. Ever since my start at the KUN, now Radboud University, I have come to realise that the technical support of our research is exceptional. In this context, special thanks go to Chris Bouwhuisen whose support I have highly appreciated over the many years of working together. I thank the lecturers and students of the Cognitive Neuroscience Master's programme for placing their trust in me, even though at times tough decisions needed to be made that caused some upheaval. Saskia Schepers as coordinator of the programme and Yvonne Schouten as secretarial assistant, both highly committed to the cause, are indispensible support staff for which I am very grateful. I would also like to thank my family and especially Truus. I'm so very glad that you have been there for me for such a long time now. Like you, I know that if they could have been here, my parents would have been proud too. Last but not in the least: many thanks to you, Hanneke. The book in which Michel Foucault described the 'linguistic turn' made a great impression on me. He called it 'Les mots et les choses'. To me you are both.

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