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Bridging the Gap between Basic and Applied Research on the Cognitive Regulation of Performance

Daniel Gopher and Asher Koriat

1.1 HISTORICAL BACKGROUND

The chapters of this volume are based on lectures and discussions presented at the seventeenth meeting of the International Association for the Study of Attention and Performance (IASAP), held in Beit Oren, Haifa, Israel, during the week of July 7—12, 1996. This gathering celebrated three decades of such meetings, the first being organized by Andries Sanders and held in the Netherlands in 1966. The success of that meeting, along with the enthusiastic dedication of its participants to the promotion and progress of the newly emerging science of cognitive psychology, led to the founding of the IASAP. The association's mission has been to enhance international collaboration and exchange through scientific meetings carefully planned and monitored by an elected executive council and an advisory board. The lectures and discussions of the meetings have been published in a series of volumes, which have served as a cumulative, state-of-the-art record for the field of attention and performance. Table 1.1 lists the dates, locations, organizers, and topics of the meetings, which clearly reflect the development and the diversity of scientific interests as well as the international spirit of the association.

1.2 ATTENTION AND PERFORMANCE XVII

In addressing the interaction between theory and application, we chose to focus on the cognitive regulation of performance, which holds high promise as a meeting ground between contemporary theories of cognitive processes and everyday challenges posed by human interactions with complex systems, and which has attracted greater interest in recent years across a wide range of research topics in psychology. The topics covered in the meeting— most notably, top-down regulatory processes and mechanisms of attention control, strategies of performance, conscious appraisal of the world, pursuit of goals, and the interplay between controlled and automatic processes in skilled performance—have become central to contemporary basic research in cognitive psychology as well as to the applied domains.

Table 1.1 List of Attention and Performance Symposia to Date

No.	Location	Year	Organizers	Topic
I	Netherlands	1966	A. F. Sanders	Attention and performance
II	Netherlands	1968	W. Koster	Reaction time
III	Netherlands	1969	A. F. Sanders	Information processing
IV	United States	1971	S. Komblum	Information processing
V	Sweden	1973	P. Rabbit and S. Domic	Information processing
VI	Sweden	1975	S. Dornic	Information processing
VII	France	1976	J. Requin	Information processing
VIII	United States	1978	R. Nickerson	information processing
IX	Great Britain	1980	J. Long and A. Baddeley	Information processing
X	Netherlands	1982	H. Bouma and D. Bouwhuis	Language processes
XI	United States	1984	M. I. Posner and O. Marin	Attention and neuropsychology
XII	Great Britain	1986	M. Coltheart	Reading
XIII	France	1988	M E. Jeannerod	Motor control
XIV	United States	1990	D. E. Meyer and S. Kornblum	Silver Jubilee: Experimental psychology and cognitive neuroscience
XV	Italy	1992	C. Umilta and M. Moskovitch	Conscious and nonconscious information processing
XVI	Japan	1994	T. Inui and J. McCelland	Information integration in perception and communication
XVII	Israel	1996	D. Gopher and A. Koriat	Cognitive regulation of performance: Theory and application

With the computer revolution and the advance of technology, we find ourselves placed more and more in supervisory, monitoring, and decision-making roles in which our cognitive regulatory abilities are of key importance. The flexibility of technology and design makes it both possible and profitable to customize designs (see for example, Gopher and Kimchi 1989; Hellander 1991; Nickerson 1992, 1995). Indeed, never before have engineers, computer programmers, and designers been so interested in and dependent or input from cognitive psychology. Are we ready for the challenge? What advice can we provide? What can we "take home" from our basic research? Such were the questions that guided the selection of presentations at Attention and Performance XVII. We believe that the time is ripe for a mutually stimulating and rewarding face-to-face encounter between basic and applied research in the area of cognitive regulation. It is for the reader to judge whether the presentations of this volume bear out our belief.

1.3 BRINGING TOGETHER THEORY AND APPLICATION

In the areas traditionally covered in Attention and Performance meetings there is certainly the potential for interaction and mutual enrichment be-

tween theory and practice. In fact, several lines of theoretically oriented experimental work in these areas have been motivated and inspired by practical problems in human-operated systems. In turn, some of the general principles of behavior discovered in the laboratory have been fruitfully applied to the real world, and there are still many more principles that have potential applications (see, for example, Boff, Kaufman, and Thomas 1986; Gopher and Kimchi 1989; Wickens 1992). Yet the general state of affairs is such that theory and practice represent the realms of two different communities (or "cultures"; see Herrman and Raybek 1997), with relatively few individuals bridging the gap between them.

This state of affairs derives in part from the differences in the motivations and environmental forces acting in each of the communities (see Intons-Peterson 1997). The theoretically oriented basic research community, which is largely university-based, is motivated by the quest to uncover the fundamental principles underlying the phenomena under investigation. New research is driven by questions raised by old research, with an attempt to enhance knowledge and provide better and more comprehensive models to account for observed phenomena. For the most part, basic research is internally motivated: it is guided by widely shared research paradigms and theoretical frameworks, and it revolves around well-established phenomena (see Newell 1973). Theoretical and empirical contributions are assessed primarily in terms of their impact on the scientific community, that is, in terms of provoking further experimental work, challenging previous conceptions, and influencing scientific thinking.

Applied work, in contrast, is externally motivated: it is driven by real-world problems that sometimes invite localized conceptualizations and ad hoc methodologies. Researchers in the applied community are generally under constant pressure to respond to specific concerns raised by technological, medical, or educational constituencies. Their success is measured by their impact and by the extent to which the products of their research are implemented.

There is also an important difference in time perspective between the theory-oriented and application-oriented communities. Whereas in basic research, time constraints are rather loose and do not constitute a major consideration, in the applied domain time is a crucial factor. Here there is almost always severe pressure to provide an answer within a very short time span. As a consequence, research carried out in response to pressing needs is likely to yield results that are of limited generalizability. What is more, that research does not always meet the standards of rigorous and controlled experimentation held by the theory-oriented community. At the same time, however, researchers concerned with application sometimes criticize laboratory-based, controlled experimentation for focusing on simple, artificial tasks that are remote from the complexities of real-world problems.

A case in point is Neisser's provocative address (1978) in which he dismissed the traditional memory work of the past century as largely worthless,

producing findings that were trivial or pointless, with little generalizability outside the laboratory. According to Neisser, memory research should have "ecological validity," that is, it should apply to naturally occurring behavior in the natural context of the real world.

Although Neisser's call for the ecological study of everyday memory met with an enthusiastic reception, it has not been immune to criticism from the proponents of controlled, laboratory-based experimentation (see, for example, Banaji and Crowder 1989). The heated debate surrounding the naturalistic versus laboratory approaches to memory (see, for example, *American Psychologist* 1991) reflects the not always hidden antagonism between the basic research and applied research communities (see Koriat and Goldsmith 1996). It is therefore critical to see how the two communities can be brought together for the benefit of both scientific knowledge and real-world application.

There are several factors that may contribute to better communication and interaction between the two communities in the area of cognitive psychology. One factor is the increased awareness among theoretically oriented researchers of the need to address questions of relevance to everyday life. "Ecological validity" is becoming something of a catchword and efforts are under way to relate many areas of cognitive psychology to the mental activities of ordinary people going about their daily lives. This effort does not necessarily imply relinquishing the goal of pure science, but rather it discloses a desire to extend the realm of scientific investigation to areas in which prospective findings are likely to have greater applicability . For example, one of the felicitous outcomes of the naturalistic-laboratory controversy in memory research is the proliferation of methodologies and research questions that have more direct bearing on real-life problems (see Cohen 1996; Gruneberg, Morris, and Sykes 1978). Following Neisser's influential call, many new areas of investigation have been opened up, and memory research is now far richer and more varied than ever before. We foresee similar developments in other areas of cognitive psychology. The challenge here, of course, is how to increase the real-world applicability of scientific inquiry without sacrificing the sacred cornerstones of good science.

A second factor that may contribute to a greater rapprochement between the basic research and applied communities is the pervasive influence of developments in technological and computerized systems on both the laboratory and the real-world environments. In the basic research environment, these advances have revolutionized the laboratory setting. With the aid of computerized technologies, the complexity and sophistication of tasks in the laboratory—and the level of control over their manipulation—have increased dramatically. Thus basic research is now able to study situations closer to some real-life settings. At the same time, the introduction of automation and computers to all aspects of our daily environment, have made many real-life tasks closer to those investigated in the laboratory. These

changes have occurred not only in complex environments such as airplane cockpits, power plant control rooms, and hospital operating rooms, but also in more mundane settings. Consider, for example, the role of computers and automation in the vast majority of office jobs or in simple household tasks such as washing clothes or cooking a meal, or even in the way we bank. Moreover, the availability of computerized systems with record-keeping capabilities in many real-life settings provides opportunities for conducting controlled studies in the field.

A third, and nontrivial factor, pushing basic science and application together is the shortage of funds for basic research. This shortage contrasts with the potential economic value of research findings in applied settings. On the one hand, the cost of conducting basic research is rising exponentially (consider, for example, neuropsychological studies using positron-emission tomography, functional magnetic resonance imaging, or even eye movement recording). On the other, funds for such research are becoming increasingly scarce. There is increasing public pressure on science to make more viable contributions to the well-being of society with the result that considerably more funds are available for research having a potential for application.

Finally, the pace of technological change is forcing the applied community to consider basic research more seriously. Applied research specifically adapted to particular technologies becomes quickly irrelevant once new technologies are introduced. In the time it takes an experiment to determine the better of two modes of information presentation on a computer screen, a third mode has already been introduced that renders the previous two obsolete. Using traditional approaches, the applied community may often miss the boat. As a consequence, there is an increasing tendency in applied setting to focus on more general principles whose application can survive the rapid technological changes. This tendency brings the applied community closer to the basic research community in the search for principles and models of broader applicability and generalization. The key concept is "There is nothing more practical than a good theory" (see Gopher and Kimchi 1989 for a detailed discussion of this point). For our part, we join with Leibowitz (1996, 366) in advocating a greater symbiosis between basic and applied research. "An approach that views the search for fundamentals and the solution of societal problems to be interdependent is worthy of serious consideration."

1.4 COGNITIVE REGULATION OF PERFORMANCE

Whereas the classical information-processing approach focused on the elementary components of tasks, the flow of information from input to output, or the basic architecture of the human processing system, interest has recently shifted to the regulatory processes underlying supervisory control functions (e.g., Allport, Styles, and Hsieh 1994; Gopher 1996; Rogers and Monsell 1995). The history of the Attention of Performance meeting presented in

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Table 1.1 bears witness to this shift. With the exception of a few presentations throughout the years, the first fourteen meetings were clearly dedicated to information processing. In contrast, Attention and Performance XV focused on conscious and nonconscious aspects of information processing, Attention and Performance XVI dealt with information integration, the present meeting centers around the cognitive regulation of performance, while Attention and Performance XVIII, to be held in Great Britain in 1998, will address the control of cognitive processes.

The information-processing approach, characteristic of most of the Attention and Performance volumes, has been dominated from its inception by a view of the cognitive system as a series of structures through which information flows. This view motivated work on the distinctive characteristics of each structure (e.g., capacity or decay time), on the mechanisms responsible for loss of information, and on the manipulation or translation of information and its transfer between structures, and so forth. This work has provided the basis for formal computational models (e.g., the pioneering work of Rumelhart and McClelland 1986) and fueled the efforts to link behavioral research with the neurophysiological study of the brain and the central nervous system (e.g., Posner et al. 1988).

Throughout the years, however, there has been an abiding interest in what might be called "executive" functions. This interest can be seen in research on the distinction between controlled and automatic processes, the allocation of attention resources, working memory, metamemory monitoring and control, language behavior, strategies of learning, remembering, and problem solving, consciousness and its function, and on top-down processes in general.

The present shift, which brings these processes to the forefront of research in cognition, is accompanied by an attempt to model their influence on behavior, using constructs, conceptual frameworks, and modeling tools similar to those employed in the classical study of information processing (e.g., Meyer and Kieras 1997; Shallice 1994). Nonetheless, it should also be recognized that the study of control and regulatory process poses many methodological, theoretical and metatheoretical challenges for cognitive psychology that may require a reconsideration of basic paradigms. There is, for example, an apparent antagonism between subject-controlled processes and experimental control, and new ways need to be found to bring more subject-controlled processes under experimental investigation. There is also a question regarding how to incorporate aspects of executive control into models of information processing (as was successfully done, for example, in models of working memory; see Baddeley 1996). Finally, the conceptualization of control processes runs the risk of reinvoking the old idea of the homunculus. Indeed, the next Attention and Performance meeting, which also focuses on cognitive control, will attempt to address the challenge of "banishing the homunculus." The problem, of course, is how to banish the homunculus without banishing from our theories the important executive

processes it instantiates. These are the challenges for research on cognitive regulation in the years to come.

1.5 OVERVIEW OF VOLUME

The organization of this volume follows the schedule of the Attention and Performance XVII meeting. Coming after the introductory chapter by Daniel Gopher and Asher Koriat, the lead chapter by David Meyer and David Kieras, based on the Association Lecture, discusses the ambitious research, project that led to the development of the executive process interactive control (EPIC) model, which can mimic performance of human operators in complex tasks and has already been applied in several domains. Parts III through VI, which constitute the body of this volume, concentrate on particular aspects of cognitive regulation. The volume concludes with a discussion chapter (part VII) by Raymond Nickerson, who served as general discussant at the meeting, reviewing major points made in the different presentations and reflecting on their implications for research and application.

Presentation and Representation or information

Human operators are required to interact with systems of ever-increasing complexity and dynamics. Computers, cars, video systems, and industrial plant control rooms, are just a few examples of such systems. A proper representation of these systems, that is, an efficient mental model of the systems and their governing operations, is critical for effective response and work procedures. How are mental models of constructed? How do they affect performance? What are the differences between the representations of experts and novices? How are these representations affected by different knowledge bases and interaction procedures?

In parallel to these questions about the operator's mental representation of the systems, there are questions that pertain to the manner in which information must be displayed to the human operator. The need to display worlds of ever-increasing complexities and the ever more versatile options for displaying information create an important opportunity for research on the design of sophisticated displays that improve human-machine interactions. What guidelines for designing effective displays can be offered by the extensive work on human processing abilities, limitations, and propensities? What are the factors that affect the ability of operators to perceive and interpret complex phenomena, and how should these factors be taken into account in designing effective displays.

Some of these questions are addressed in part III, In their focus on application chapter (chapter 3), Irving Biederman, Suresh Subramaniam, Peter Kalocsai, and Moshe Bar discuss the critical problem of how objects can be classified regardless of viewpoint and propose a subordinate-level information taxonomy. In chapter 4, Christopher Wickens analyzes the implications

of exocentric and egocentric reference frames in spatial orientation on the design of maps. In chapter 5, Shinsuke Shimojo, Okihide Hikosaka, and Satoru Miyauchi focus on the line motion effect in terms of the distinction between automatic-involuntary and controlled-voluntary processes of attention. In chapter 6 Roberta Klatzky and Susan Lederman introduce the haptic glance, reviewing extensive experimental work on the properties of objects available from initial contact and how these are used to determine object identity and to guide manipulation, and discussing possible implications for augmenting traditional modes of display. In chapter 7, John Flach describes a "meaning processing" approach to the design of displays, anchored in the philosophy of ecological psychology. In chapter 8, Neville Moray addresses classes of mental models people develop when interacting with complex tasks, examining formal approaches to explicate and describe such models. Finally, in chapter 9, John Long uses an example from the design problems involved in planning and control of task load in medical reception to illustrate the crucial importance of issues of cognitive analysis and representation.

Cognitive Regulation of Acquisition and Performance.

Part IV focuses on the choice of strategies for performing a task in accordance with task demands, the allocation of attention to different tasks, the on-line monitoring of task performance, and the control over one's own actions. Determining the nature and extent of strategic control in proficient performance, and how such control is developed with proper training, represents one of the main challenges that applied psychology has posed for basic cognitive research. Of special significance is the interplay between top-down strategic control and bottom-up automatic processes in proficient behavior. Examples of applied tasks that call for such considerations are (1) monitoring and supervisory behavior in industrial process control rooms (power and chemical plants, air traffic control towers); (2) interaction with dynamic systems, responding to time changes and control dynamics, in tasks such as flying, navigating, and driving. In their focus on application chapter (chapter 10), Alice Barnes, Thomas Nelson, John Dunlosky, Giuliana Mazzoni, and Louis Narens present an integrative conceptual framework that specifies the various metacognitive processes involved in retrieval and that brings to the fore the dynamic interplay between monitoring and control operations. In Chapter 11, Lynne Reder and Christian Schunn-discuss the findings that people vary in their ability to adaptively shift strategies in response to changing features of the task environment and that this regulatory ability apparently differs from the component abilities required for the performance of specific tasks. In chapter 12, Ido Erev and Daniel Gopher offer a cognitive game-theoretic analysis of attention strategies, abilities, and incentives that combines concepts and constructs from signal detection, learning research, and behavioral game theory to create a unified framework for assessing the different determinants of acquisition and performance. In chapter 13, Morris

Goldsmith and Asher Koriat examine the monitoring and control processes underlying people's memory reporting, and show how rememberers use these processes to regulate both the quantity and the accuracy of their memory performance. Finally, in chapter 14, Wayne Shebilske, Barry Goettl, and J. Wesley Regian summarize the results of an extensive experimental program conducted by the U.S. Air Force to assess individual and group protocols for training complex skills in laboratory and applied settings, and examines their theoretical implications.

Consciousness and Behavior

The relationship between consciousness and behavior is a long-standing theoretical issue in psychology that has recently attracted interest in connection with the distinction between implicit and explicit cognition. At the same time, the dependability of subjective reports, particularly the assessment of one's own capabilities and performance, represents a major concern of applied researchers. Subjective reports are important not only because they serve as a tool for assessing performance, but also because they often provide the basis for regulating one's own performance. Self-monitoring occurs at many stages of information processing. For example, people monitor the extent to which they have mastered different tasks and allocate study time accordingly. They assess the likelihood that an unrecallable piece of information will be recovered and decide whether to continue searching for it or to give up, they judge whether a planned act has already been performed in order not to repeat it, and so forth. Many errors often ensue from insufficient or inaccurate monitoring of behavior.

Subjective reports constitute a very important source of information in many field applications, and their dependability is of major concern. This can be clearly seen in the judicial system, which is highly dependent on witnesses' accounts of their experiences, but it is equally relevant in many managerial and decision-making positions. In the design and evaluation of engineering systems, human performance specialists traditionally rely both on subjective and behavioral measures. These often do not agree. How should discrepancies between subjective measures and performance measures be treated? What are the sources of such discrepancies?

Part V addresses these and related questions. In his focus on application chapter (chapter 15), which assumes that the assessment of one's own competence is no less important in many real-world settings than one's actual competence, Robert Bjork presents an incisive analysis of the processes underlying this assessment and examines how these processes can often lead to illusions of comprehension and competence. In chapter 16, Larry Jacoby, Brian McElree and Torn Trainham discuss whether automatic processes can produce an accessibility bias whose effects are independent of recollection and present a model that accounts for results obtained by using the process dissociation procedure. In chapter 17, Wolfgang Schneider reviews findings

and theories about the development of declarative and procedural metamemory and examines intervention procedures that attempt' to improve metamemory in children and adolescents. In chapter 18, Colleen Kelley explores the thesis that one's subjective experience in solving a problem, answering a question, or comprehending a text is often a useful basis for making predictions about the difficulty of these tasks for others and concludes that subjective experience can be misled by spurious influences, leading to the "illusion of simplicity." In chapter 19, which offers a close look at one of the exemplary attempts to bridge between theory and application, Ronald Fisher describes his and Edward Geiselman's development of effective methods of interviewing. Finally, in chapter 20, Dan Zakay, Richard Block, and Jehoshu Tsal discuss the processes underlying duration estimation and examine how duration judgments can be used to reflect the workload demands of everyday tasks.

Special Populations: Aging and Neurological Disorders

Attention control and cognitive functions are greatly impaired as a result of aging and a variety of neurological and brain disorders. How has basic research in cognition been applied to these types of problems?

Part VI focuses on two aspects of control: (1) rehabilitation of control on a task impaired due to aging or neurological problems; and (2) using controlled processes to perform a task that could previously be performed with little control. In their focus on application chapter (chapter 21), Fergus Craik and Nicole Anderson review findings and theories in cognitive aging, and examine some of their actual and potential applications as far as the effects of automaticity, environmental support, and the value of training. In chapter 22, which also relates to many of the issues raised in part IV, Arthur Kramer, John Larish, Timothy Weber, and Lynn Bardel present an impressive set of experiments supporting the thesis that executive control skills can be trained. They compare the development of such skills in young and old adults, and the extent to which the development of control abilities in old age can reduce the performance gap between young and old. In chapter 23, Lynn Hashpr, Rose Zacks. and Cynthia May present their theory and recent findings on the effects of age and circadian arousal in terms of a model of the inhibitory control over the contents of working memory. Chapters 24—26 concern neurological deficits in control—and their rehabilitation. Examining the recovery of function after brain damage. In chapter 24, Ian Robertson focuses on the role of attention and competitive inhibiton and stresses the need for adequate theories to determine the optimal input for effective rehabilitation. In chapter *25,* Heiner Deubel reports an elegant set of experiments that distinguish between the adaptive control of reactive, volitional, and memory-guided saccades. In chapter 26, the last in part VI, Elisabetta Ladavas examines the role of spatial attention in neglect dyslexia and recent findings that suggest an interaction between attention and reading. Lexical

and semantic access are demonstrated for words that patients are unable to read.

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