



UPPSALA
UNIVERSITET

*Digital Comprehensive Summaries of Uppsala Dissertations
from the Faculty of Social Sciences 52*

Modes of Apprehension, and Indicators thereof, in Visual Discrimination of Relative Mass

ISABELL ANDERSSON



ACTA
UNIVERSITATIS
UPSALIENSIS
UPPSALA
2009

ISSN 1652-9030
ISBN 978-91-554-7602-1
urn:nbn:se:uu:diva-108214

Dissertation presented at Uppsala University to be publicly examined in Sal VIII, Universitetshuset, Uppsala, Friday, October 16, 2009 at 13:00 for the degree of Doctor of Philosophy. The examination will be conducted in English.

Abstract

Andersson, I. 2009. Modes of Apprehension, and Indicators thereof, in Visual Discrimination of Relative Mass. Acta Universitatis Upsaliensis. *Digital Comprehensive Summaries of Uppsala Dissertations from the Faculty of Social Sciences* 52. Uppsala. ISBN 978-91-554-7602-1.

Perception is a fundamental function because it allows organisms to be in contact with the environment and adjust to environmental conditions. Humans also possess higher intellectual functions, which allow for elaborate handling of perceptually obtained information. The thesis concerns a distinction between an inferential ("cognitive") mode and a (direct-)perceptual mode of apprehension, and a notion of perceptual skill acquisition as a transition from the inferential to the perceptual mode. The mode distinction and the mode-transition model was formulated by Runeson, Juslin, and Olsson (2000) within the ecological direct-perception framework (Gibson, 1966, 1979).

The modes of apprehension were investigated in an experimental paradigm that concerned visual perception of the relative mass of two colliding objects. The relative mass is specified by an optical variable in the collision movement pattern, which observers may pick up while functioning in the perceptual mode. However, novices often rely on other, nonspecifying, optical variables that may constitute cues that are used in the inferential mode (Runeson et al., 2000).

Four tentative mode indicators were employed: participants' realism of confidence, introspective mode reports, amplitudes of brain event-related potentials, and response times. Generally, the results did not support the mode-transition model of skill acquisition. Furthermore, results suggested that reliance both on the specifying and nonspecifying variables might have occurred either in the inferential or in the perceptual mode. However, the mode indicators may not have captured mode as intended. For instance, the discriminability of used optical variables, and not the mode of apprehension, may have affected both amplitudes of event-related potentials and mode reports.

It is argued that the mode-transition model and the distinction between two modes of apprehension should be further investigated employing other methodologies, and, furthermore, that the mode distinction has a place within an ecological framework.

Keywords: Modes of apprehension, dynamical-event perception, ecological psychology

Isabell Andersson, Department of Psychology, Box 1225, Uppsala University, SE-75142 Uppsala, Sweden

© Isabell Andersson 2009

ISSN 1652-9030

ISBN 978-91-554-7602-1

urn:nbn:se:uu:diva-108214 (<http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-108214>)

List of papers

This thesis is based on the following studies, which will be referred to in the text by their Roman numerals:

- I Runeson, S., & Andersson, I. E. K. (2007). Achievement of specificational information usage with true and false feedback in learning a visual relative-mass discrimination task. *Journal of Experimental Psychology: Human Perception and Performance*, 33, 163-182.
- II Andersson, I. E. K., & Runeson, S. (2008). Realism of confidence, modes of apprehension, and variable-use in visual discrimination of relative mass. *Ecological Psychology*, 20, 1-30.
- III Andersson, I. E. K., Kreegipuu, K., Allik, J., & Runeson, S. (2009). *Phenomenological reports, event-related potentials, and response times pertaining to mode of apprehension in visual discrimination of relative mass.* (manuscript)
- IV Andersson, I. E. K. (2009). Realism of confidence and phenomenological reports are not congruent indicators of modes of apprehension in visual discrimination of relative mass. *Ecological Psychology*, 21, 218-244.

Contents

Introduction.....	7
Direct perception.....	7
Perceptual errors and nonspecifying variables	9
Perceptual learning	10
Indirect perception.....	12
Modes of apprehension and the mode-transition model.....	14
What are the inferences in the inferential mode of apprehension?	15
Mode transition: a shift from "thinking" to "perceiving"	16
Aims of the thesis.....	18
Method.....	19
Experimental paradigm	19
Candidate informational variables	19
Equipment and simulations.....	22
Tentative indicators of mode of apprehension	22
Variable usage	23
Realism of confidence	24
Phenomenological mode reports.....	26
Event-related potentials and response times	28
Empirical studies.....	31
Study I.....	31
Results	32
Study II.....	35
Results	36
Study III	39
Results	40
Study IV: Experiment 1.....	47
Results	48
Study IV: Experiment 2.....	49
Results	50
Study IV: Experiment 3.....	53
Results	53
Discussion.....	55

Main findings and their limitations	55
Variable usage and learning.....	55
Realism of confidence	57
Mode reports.....	62
Response times	63
Event-related potentials	64
Mode reports and over/underconfidence scores combined.....	65
Conclusions	66
Direct perception and the inferential mode	68
Acknowledgements.....	73
References.....	74

Introduction

“The constantly looming catastrophes of the intellect would be found more often developing into catastrophes of action were it not for the mellowing effect of the darker, more feeling-like and thus more dramatically convincing primordial (that is, perceptual) layers of cognitive adjustment.” (Brunswik, 1956, p. 93)

"Merely probable information, clues or cues, is not as satisfying for the perceptual system as the achieving of clarity...but guessing does occur in highly complex situations and the individual may sometimes have to be content with it." (Gibson, 1966, p. 304)

Perception is a fundamental function for all organisms. It allows organisms to be in contact with the environment and to adjust to environmental conditions. In addition, humans possess higher intellectual functions, which allow for elaborate handling of perceptually obtained information and of abstract entities. However, neither perception nor intellectual functioning always results in perfect adjustment to the environment, and both may improve with extended experience and practice.

This thesis concerns perceptual skill acquisition, and more specifically an idea of perceptual skill acquisition as a transition from an inferential to a perceptual mode of apprehension (Runeson, Juslin, & Olsson, 2000). This mode-transition model of perceptual skill acquisition was formulated within the ecological direct-perception framework (Gibson, 1966, 1979; Michaels & Carello, 1981). Before describing the modes of apprehension and the mode-transition model, the ideas and concepts of the direct-perception approach are presented and contrasted to indirect approaches to perception.

Direct perception

The direct-perception approach portrays perception as the *extraction of information* inherent in energy patterns that surrounds the organism (Gibson, 1966, 1979). The extraction of information occurs through *smart mechanisms*, which register apparently complex informational variables in the ambient stimulus flux, without prior detection and computation on simpler variables (Runeson, 1977; see also Michaels & Carello, 1981). Perception is said

to be direct because unconscious inferences or other types of mental computations are superfluous due to the *specificity* of information.

Information, in the Gibsonian sense, is a relation between energy (such as light, vibrations, etc.) and properties of the environment (such as surfaces, substances, etc.) (cf. Chemero, 2003). Energy fields are structured by sources in the environment. When described at the appropriate level, stimulation is thus not ambiguous with respect to environmental properties. Rather, it stands in a one-to-one relation to those properties, providing specificity of information. Informational specification is found in *invariants*, which are patterns of stimulation that co-vary with environmental properties, and that remain unchanged by circumstantial transformations over time or space (Gibson, 1966, 1979; Michaels & Carello, 1981; cf. Rogers, 2000). That is, spatio-temporal structures of energy provide specification of the environment. By detection and pick-up of specificational invariants, perceivers become informed about useful environmental properties, or about perceiver-relevant action possibilities (affordances) (Gibson, 1979; cf. Bingham, 2000).

The specificity of information is granted by regularities that prevail in the world, that is, *constraints* (Runeson, 1988, 1989; Chemero, 2003). Constraints can be universal, such as general laws of optics and physics (e.g., laws of wave propagation), or local ecological constraints, such as the regular distribution of texture elements on surfaces. In addition, cultural conventions and rules can provide more confined constraints. Since specificity of information is depending on pertinent constraints that prevail, specificity will vary in degree of universality depending on the generality of constraints. The perceptual system may exploit any regularity (Warren, 2005), and it has evolved to take advantage of global and specific ecological constraints (Runeson, 1994). Individuals may also learn to take advantage of more local constraints, such as regularities in an experimental environment (e.g., Jacobs, Runeson, & Michaels, 2001).

An instance of informational specificity, granted by constraints in the form of the laws of physics, is expressed by the principle of *kinematic specification of dynamics* (the KSD principle). The KSD principle states that kinematic patterns (motions) specify dynamic properties (causal factors such as force, mass, and friction) of moving objects (Runeson, 1977/1983; Runeson & Frykholm, 1983). As argued by Runeson (1994), it is often more action relevant to perceive dynamic properties such as mass of objects, than kinematic properties such as particular motions. Often, dynamic properties are lasting characteristics of objects, and by becoming informed about such properties, an observer may to some extent predict future movements of the objects involved, which facilitates future interaction with the objects.¹ Thus,

¹ However, this does imply that motions as such may not be relevant to observers, nor that motions as such are never perceived (cf. Study I and IV in this thesis).

there is incentive to evolutionary development of perceptual systems that can respond to KSD-type of information.

That observers can take advantage of KSD-type of information has been demonstrated in studies of visual perception of weight of lifted boxes, and of sex and identity of point-light walkers (Kozlowski & Cutting, 1977; Runeson & Frykholm, 1981, 1983). As will be discussed later, it has also been demonstrated in visual perception of relative mass of colliding objects (Cohen, 2006; Jacobs, Michaels, & Runeson, 2000; Jacobs, Runeson, & Michaels, 2001; Runeson et al., 2000; Runeson & Vedeler, 1993).

Perceptual errors and nonspecifying variables

Generally, in the direct-perception view, perception is approached from the "perfectionist end" and perception is seen as "approximating perfection" (Runeson et al., 2000, p. 531), given that the observer is allowed to explore the optic array (for instance by moving around) (Gibson, 1966). Nevertheless, perceptual achievements are not always perfect. According to Gibson (1966), there are two reasons perception may fail; one is because adequate information is not being picked up due to deficient physiological processes, the other is because the available information is inadequate.

Examples of misperceptions are mirages, and when a straight stick appears bent when part of it is submerged in water (Gibson, 1966). In both cases, information is inadequate because the normal constraint of the linear propagation of light is broken due to reflection or refraction. Constraints can also be artificially broken, such as when creating a "swinging room" (Lee & Aronson, 1974) in which the normally prevailing coupling between the ground and the walls is de-coupled, or an Ames' distorted room which is deliberately constructed to yield (deceptive) specificity of a normal rectangular room when viewed from one particular position (cf. Runeson, 1988). Because the perceptual system relies on the normally prevailing ecological constraints, such constructions result in anomalous and in some sense erroneous² perception (cf. Jacobs, Runeson, & Andersson, 2001).

However, errors may occur despite that both the physiological processes and available information are adequate. In some cases, observers rely on variables that do not specify a specific environmental property although a specifying variable is available (cf. Jacobs & Michaels, 2002; Withagen, 2004). Such variables may be more or less related to the property but lacks the one-to-one correspondence that the specifying variable has, that is, "a single value of the variable can go together with several states of the property" (Jacobs & Michaels, 2001, p. 564). Runeson (1989) referred to such

² Some researchers in the Gibsonian tradition claim that "errors" and "misperceptions" do not occur if one considers evolution and the learning history of the perceiver (e.g., Michaels & Carello, 1981, cf., Cutting, 1982)

variables as *incomplete invariants*. An incomplete invariant is an informational variable that is granted by constraints that do not apply throughout the relevant environment, leading to a less than perfect correlation between the variable and a specific environmental property. For a subset of cases, or in a local region of the environment, an incomplete invariant may provide specificity however, and thus become a complete invariant (i.e., a specifying variable) in this limited region (e.g., Jacobs, Runeson, & Michaels, 2001; Runeson, 1989). Jacobs and Michaels (2001) used the term *nonspecifying variables* for incomplete invariants, which also is the term used in this thesis.

Why would nonspecifying variables be used when they lead to less than perfect perceptual achievements or to misperceptions and errors? As pointed out by Withagen (2004), certain relevant environmental properties might not be specified by informational variables. In such cases, perceivers have no option but to pick up variables that are non-specific to the property. In cases when specifying information exists, it may nevertheless be non-exploited due to an unadapted perceptual system. Moreover, because nonspecifying variables may be quite informative, such variables may be picked up because they lead to “fairly accurate” perception (Withagen, 2004, p. 242). Gibson (1966) pointed at the economy in perception, “the information registered about objects and events becomes only what is needed, not all that could be obtained” (p. 286). However, with extended exposure or practice, perceivers may learn to pick up variables that are more informative, and thus improve in their perceptions.

Perceptual learning

In the direct-perception view, perceptual learning is about differentiation of previously undifferentiated stimuli, or about changes in what variable in stimulation that is exploited.³ An example of the former is a wine connoisseur that has learned to differentiate variables of chemical stimulation, which for the novice are undifferentiated (Gibson & Gibson, 1955). Examples of the latter are found in learning studies concerning visual perception of the pulling force of a stick-figure (e.g., Michaels & de Vries, 1998), length of wielded non-seen objects (e.g., Michaels, Arzamarski, Isenhower, & Jacobs, 2008; Wagman, Shockley, Riley, & Turvey, 2001), visually guided braking (Fajen & Devaney, 2006), and visual discrimination of relative mass of colliding objects (e.g., Jacobs et al., 2000; Jacobs, Runeson, & Michaels, 2001; Runeson et al., 2000). In these studies, observers changed in what variable they used for their judgments. As novices, they generally relied on nonspecifying variables, however not always the same for all individuals (Jacobs &

³ Yet another type of learning is *calibration*, which concerns scaling of perception or action relative the exploited informational variable (e.g., Bingham & Pagano, 1998; Withagen & Michaels, 2004).

Michaels, 2001; Jacobs et al., 2000; Jacobs, Runeson, & Michaels, 2001; Michaels & de Vries, 1998; Withagen & Michaels, 2005). During practice, observers learned to detect the specifying variable, or a nonspecifying variable that correlated higher with the property that they were to judge than the initial variable did. That is, with practice, generally observers converge on relying on variables that are more informative.

Perceptual learning due to convergence on more informative variables is referred to as the *education of attention*. Attention is what controls detection of information and enables noticing of critical differences and less noticing of irrelevancies (Michaels & Carello, 1981; Gibson, 1966, p. 52). The environment influences attention, "interesting bits of structure, particularly motions, *draw* the foveas toward them" (Gibson, 1966, p. 260). However, attention is also influenced by observers' intentions (Shaw & Kinsella-Shaw, 1988). Perceptual learning will then also involve the *education of intention* (Jacobs & Michaels, 2002). With practice, perceivers will learn and improve in which perception they will intend to actualize. This will partially determine where attention will be directed and thus what variables will be exploited. As pointed out by Jacobs and Michaels (2002), intentions constrain task situations and, indirectly, intentions determine which is the specifying variable in a particular situation. "Given intentions, some variables can be said to be information in a specificational sense and others cannot." (p. 134) In perception experiments, it is generally assumed that participants intend to perceive the property they are instructed to judge.

Above, perceptual learning and the education of attention were said to be influenced both by the environment and by the perceiver's intentions. However, the earlier ecological theories were not explicit about how learning would come about (cf. Michaels & Beek, 1995). The recent *direct learning* model (Jacobs & Michaels, 2007; Michaels et al., 2008) suggests that learning is guided by *convergence information*. Convergence information consists of a "higher-order relation of detectable quantities", defined over a time interval or over a number of trials. The higher-order relation would involve certain properties of the environment, perceptual judgments, and feedback. Over time, the perceiver would detect convergence information which would "push" him or her to attend to more useful informational variables, ultimately the specifying variable. Notably, no mediating "cognitive" processes are needed for learning to occur.

Indirect perception

The indirect⁴ approach to perception belongs to a tradition older than the direct-perception approach. The major differences between the approaches concern how the stimulation is portrayed, and the involvement of mediating processes between stimulation and percepts. Moreover, whereas in the direct view perception is about "keeping-in-touch with the world" (Gibson, 1979, p. 239), perception in the indirect views is about creating a mental representation of the environment (Epstein, 1995).

In the indirect views, stimulation is seen as ambiguous with respect to the environment. A given event or property in the environment would give rise to a specific retinal pattern, but a given retinal pattern could be caused by numerous distal events or properties; the *inverse projection problem* (see Epstein, 1995). To solve the inverse projection problem, and thus to become informed about the environment, the perceiver must somehow disambiguate the sensations. Often, the problem becomes how to construct a three-dimensional representation from the two-dimensional retinal image. Indirect theories mainly focus on how this disambiguation and construction would occur.

Helmholtz (1867/1925) suggested that the perceptual system relies on *unconscious inferences* to solve the inverse projection problem (see Allik & Konstabel, 2005, for a discussion of the origins of this term). The inferences are built on premises such as "under normal conditions, only 3-D structures generate patterns of binocular disparity". If retinal stimulation indeed forms a pattern of binocular disparity, the conclusion is drawn that "the object in my visual field is very likely a 3-D structure" (from Epstein, 1995). Helmholtz' idea of unconscious inferences in perception is the core in cognitive constructivist notions of perception (e.g., Bruner, 1957; Brunswik, 1956; Knill, Kersten, & Yuille, 1996; Rock, 1983). The inferences resemble the cognitive operations used for conscious problem solving (see Kubovy, Epstein, & Gepshtein, 2003). For example, in Rock's (1983) view "perception is intelligent in that it is based on operations similar to those that characterize thought" (p. 1).

Generally, the inferences, and thus the perceptual outcomes, rely on internal premises, stored knowledge, or assumptions about the environment and about how stimulation is structured vis-à-vis the environment. For example, in discussing anomalous perception Rock (1983) wrote "the perceptual system 'knows' certain laws of optics that normally obtain and then 'interprets' seeming departures from these laws in such a way as to be compatible with them" (p. 10). In more recent indirect views of perception, as in the Bayesian approach (Knill et al., 1996; Kersten, Mamassian, Yuille, 2004), internal

⁴ Gibson (1979), however, used the term "indirect perception" for perception through pictures, x-ray images, microscopes and telescopes etc.

assumptions also about the structure of the environment are central (cf. Kubovy et al., 2003). "Explicit models of world structure (i.e., regularities in properties of the world) are needed to completely characterize both the information provided in images for perception and the actual inferences made by the visual system in the course of perception" (Knill et al., 1996, p. 2). According to the Bayesian model of perception, the perceptual outcome is in the form of a probability distribution, which is determined in part by a coding scheme based on the physics of light reflection, refraction etc. and signal corruption, and in part by the statistical structure of the world (the "prior probability distribution"). One example of such a "prior" is the assumption that light is coming from above (Kersten et al., 2004, p. 283).

According to the computational constructivist approach (e.g., Marr, 1982), perception does rely neither on stored knowledge and assumptions, nor on cognitive operations. Instead, computations in the visual system *embody* certain "natural constraints" in the interpretation of the retinal image. Examples of such natural constraints are that matter is predominately coherent, that surfaces of objects most often are rigid, and that substances tend to be opaque (Pylyshyn, 1999, p. 355). These environmental regularities have acted to shape computational modules in the visual system, "the visual system does not need to access an explicit encoding of the constraint: it simply does what it is wired to do" (Pylyshyn, 1999, p. 354).

The premises, assumptions, and "natural constraints" in the indirect theories resemble, and seem to have the same function as, the global and ecological constraints in the direct-perception model. A major difference is, however, that in the indirect views those elements are said to reside within the organism, whereas in the direct view the constraints reside outside the organism, and the *consequences* of which are exploited by the perceptual system (cf. Jacobs, Runeson, & Andersson, 2001; Kubovy & Epstein, 2001; in response to Shepard, 2001).

There have been attempts to reconcile the indirect and direct views. For instance, Braunstein (2002) pointed out that the term "inference" in the indirect theories should not necessarily be taken to imply that perception is intelligent and thought-like. Instead, inferential mechanisms should be seen as *instantiating rules* (which is explicit in the computational constructivist models); thereby they will constitute smart mechanisms (Runeson, 1977). "If the concept of inference is completely separated from intelligence, thought, and active use of knowledge, and is allowed to encompass smart mechanisms and resonance, there is no need for direct perception theorists to object to inference." (Braunstein, 2002, p. 99) (See also Hatfield, 1988, 1990; Norman, 2002; Wagemans, 1990.) It can also be noted that proponents of indirect perception usually hold that *something* is "directly perceived". In an article that criticized the direct-perception approach, Fodor and Pylyshyn (1981) noted that "even theories that hold that perception of many properties is inferentially mediated must assume that the detection of *some* properties is

direct (in the sense of *not* inferentially mediated). Fundamentally, this is because inferences are processes in which one belief causes another. Unless some beliefs are fixed in some way other than by inference, it is hard to see how the inferential processes could get started." (p. 155) (see also Michaels & Carello, 1981, p. 183).

Modes of apprehension and the mode-transition model

Runeson et al. (2000) proposed that humans function in either of two qualitatively different modes when apprehending the environment. One is the *perceptual mode*, which entails pick up of information that directly leads to judgments or actions. The other is the *inferential mode*, which entails pick up of cues or clues that via rules or inferences lead to judgments or actions. The *mode-transition model* of perceptual skill acquisition is a complement to direct perception notions of perceptual learning, as discussed above. Perceptual skill acquisition would proceed as a transition from the inferential to the perceptual mode, together with a shift from low- to high-quality information usage. "True beginners start out in an inferential-reasoning mode, in which they are groping for an adequate way to master the task. Sooner or later they discover a direct 'intuitive' mode of attention" (Runeson et al., 2000, p. 550). For novices, the inferential mode would provide "a pedagogical vehicle with which observers explore the task situation and precipitate feedback, allowing their perceptual system to discover new possibilities" (p. 550). The mode-transition model thus differs from the direct learning model in that inferences play a role in the learning process, and thus that learning is not solely guided by information. However, as indicated by the quote above, not only inferences would influence the skill acquisition process. One essential part of perceptual skill acquisition would be perceptual "discovery", that is, detection of informational variables.

The mode distinction sprang out of a debate between proponents of the direct-perception approach (Runeson, 1995; Runeson & Vedeler, 1993) and proponents of a cue-heuristic approach (Gilden, 1991; Gilden & Proffitt, 1989, 1994; Proffitt & Gilden, 1989) regarding the informational basis in dynamic-event perception. Gilden and Proffitt argued that only simple properties of events, such as directions and speeds, are available for perception, whereas "multidimensional" properties, such as velocity-vector components in collisions, are not. Thus, when asked to judge the relative mass of objects involved in collisions, observers are left with impressions of speed and directions of the objects' trajectories. Observers then have to resort to heuristics, one for each category of information, to make their judgments. Runeson et al. (2000; Runeson & Vedeler, 1993) showed that Gilden and Proffitt's cue-heuristic explanation applied only to novices. After practice, observers

performed better than expected from Gildea and Proffitt's model, and their performance fitted better to the mass ratio invariant model.

What are the inferences in the inferential mode of apprehension?

What would characterize the inferential mode? Runeson et al.'s (2000) article was directed mainly to a cue-heuristically inclined audience, and aimed to show that visual pick up of specificational information about dynamics does in fact occur for experienced perceivers (Runeson, personal communication, 2009). However, they did not go into details of what inferential-mode functioning would consist of. Instead, it seems they accepted Gildea and Proffitt's (1989) model of dynamic event perception as being an example of novices' inferential-mode functioning, "the general character of Gildea and Proffitt's cue-heuristic model may be useful in describing the explorative endeavors of beginners on unfamiliar tasks" (Runeson et al., 2000, p. 550).

According to Gildea and Proffitt's cue model, people do have some "common-sense notions about how the world operates", and they make dynamic judgments "on the basis of heuristics that articulate these notions" (Gildea & Proffitt, 1989, p. 374). According to Gildea (1991) "the mapping [between kinematics and dynamics] that people apparently use is based on a small set of separate ideas that they have about the way the world works." (p. 557) When relying on Gildea and Proffitt's model as describing inferential mode-functioning, it seems that the heuristics, or inferences, used in the inferential mode would be deliberately used rules. The inferences would thus not consist of the "unconscious inferences" that are the essential component of indirect notions of perception.

According to Hecht (1996) however, the heuristics in Gildea and Proffitt's model would indeed be "unconscious perceptual heuristics" (p. 65). Hecht (2000) stated that "the term heuristic is suggestive of rules being consciously applied by the perceiver or by some homunculus looking at the retinal image, but this it not meant. Perceptual heuristics . . . are usually not available to introspection." (p. 4) Thus, Gildea and Proffitt's model seems to fall under the indirect notion of perception.

The approach taken in this thesis is that the inferences in the inferential mode are not unconscious inferences, or "perceptual heuristics", carried out in the perceptual system. Instead, the inferences would be deliberately and consciously applied rules or heuristics.⁵ Inferential-mode functioning entails pick up of nonspecifying variables, which act as cues or clues, enabling inferring of unknown properties from the perceptually known. To function inferentially, observers need to have, or to form, an idea about how the non-

⁵ Hence, the introspection-based indicators of the modes that will be employed in the thesis (realism of confidence and mode reports) are not suited for testing Gildea and Proffitt's (1989) model, providing that their "perceptual heuristics" are unavailable for introspection.

specifying variables are related to the sought-after property. Perceptual-mode functioning, in contrast, entails pick up and usage of variables that specify, or that from the observer's point of view seem to specify, the sought-after property. Because the information seems to specify the sought-after property, it is directly used or acted upon. Thus, in both modes, pick up of information would occur, but the difference is in what kind of information is obtained and, more critically, *how* observers use information; directly leading to judgments or leading to judgments via rules. Moreover, the inferential mode is not a case of perception as it is conceptualized by the indirect theories, and the mode distinction is not a distinction between direct and indirect perception.

Mode transition: a shift from "thinking" to "perceiving"

As noted above, the mode-transition model of perceptual skill acquisition involves both a change in the effective variable for perception and a change in the mode of apprehension. Runeson et al. (2000) pointed to similarities between the mode-transition model and models of skill acquisition in motor tasks. In motor tasks, skill acquisition would proceed by the actor "freezing" all but a few of the bodily degrees of freedom, which allows deliberate control of the remaining parts (e.g., Bernstein, 1967; Fowler & Turvey, 1978; Vereijken, van Emmerik, Whiting, & Newell, 1992). Although the resulting movements are inefficient, those movements help reveal the dynamic characteristics of the action system, which in turn allows the actor or the motor system to discover a task-specific way of coordination. Analogous to the freezing of bodily degrees of freedom, the inferential use of cues would capture only limited features of the available information. Use of cues would lead to "a suggestive pattern of success and failure", which, in turn, would allow the perceptual system to discover "a stable, qualitatively different, and more efficient mode of cognizing" (Runeson et al., 2000, p. 550). Thus, the mode transition entails perceptual discovery of task-relevant information, after a phase of deliberate exploration of the task environment.

The notion of perceptual skill acquisition as a change from consciously controlled performance to performance less directly subject to conscious control surfaces also in other views on skill acquisition. For example, in Anderson's ACT model (1982), cognitive skill acquisition proceeds as a transition from a declarative to a procedural stage, in which knowledge is gradually converted from declarative to procedural form. Declarative knowledge is a set of facts about the skill that are kept in working memory, and that often is verbally mediated. Procedural knowledge consists of procedures or skills specific to the task at hand, which directly apply the knowledge. (See also Fitts & Posner, 1967; Schneider & Shiffrin, 1977, for similar models of skill acquisition in visuo-motor tasks and in visual search, respectively.) The mode-transition model also resembles Dreyfus and Dreyfus

(1986) view on the development of expertise in that both involve changes in what information the performer considers; from limited features to more holistic information. Moreover, behavior changes from being deliberate and rule-based, to being "intuitive" requiring no awareness. Functioning in the perceptual mode, like the expert functioning of Dreyfus and Dreyfus, would be "without awareness of how it comes about, relying on the inherent sophistication of one's action or perception system" (Runeson et al. 2000, p. 551).

Runeson et al.'s (2000) distinction between two modes of apprehension also resembles Heft's (1993) distinction between perceptual and analytical judgments. Heft asked observers to estimate whether a seen object was within reach or not. When the estimates were made the focal task, observers overestimated their reach, whereas when the estimates were made a subsidiary part of another task, they became very accurate. Heft suggested that observers adopted an "analytical attitude" in the focal condition, which interfered with perceptual processes. He pointed out that "psychological processes can be conceptualized as modes of adaptive functioning in relation to the ongoing flow of events...Among these psychological processes is the capacity to 'step outside' of this flow" (p. 259). The analytical attitude and the ability to step out of a flow of events would also characterize the inferential mode of apprehension.

Brunswik made a distinction between intuitive and analytical modes of cognition, or between "perception" and "thinking" (1955, 1956, 1966; Hammond, 1966, p. 47). In contrast to Gibson's direct-perception approach, according to Brunswik not only thinking, but also perception relies on cues and inferences (for a comparison of Gibson's and Brunswik's approaches, see Vicente, 2003). "Perception and thinking ... emerge as different forms of imperfect inferences regarding the environment, subsumable to a common behavior model patterned upon reasoning" (Brunswik, 1955, p. 108). Perception would rely on integration of many cues, which would lead to a "soft and smudgy" error profile, with a relative freedom of large errors. Thinking, in contrast, would be more "single-track", and lead to a large proportion of perfect judgments, with no near-misses, but also to occasional large or even "bizarre" judgments (Brunswik, 1966, p. 489; see also Juslin & Olsson, 1997, for a similar distinction between *Thurstonian* and *Brunswikian* origins of error).

Although Brunswik's view on perception differs from the direct-perception approach, his predictions regarding the error profile for perception and thinking might be relevant also for distinguishing between the two modes of apprehension. Before examining this possibility, and other potential indicators of the modes, the aims of the thesis and the experimental paradigm employed are presented.

Aims of the thesis

The main aims were to examine the mode-transition model of perceptual skill acquisition in discrimination of relative mass of colliding objects (Runeson et al., 2000) and to further explore possible methods to empirically distinguish the modes of apprehension. Do people change from inferential to perceptual functioning during practice? How can we know whether such a change occurred? These questions were addressed in a series of four studies, each with specific goals:

Study I served as a prelude, focusing on variable usage and how it is affected by feedback. During practice, do observers change in the variable relied upon when judging relative mass? Would such a change be entirely feedback dependent?

Study II tested the mode-transition model and whether the modes were related to which variables observers used. During practice, do observers change from inferential to perceptual functioning? Are nonspecifying variables used in the inferential or the perceptual mode? Realism of confidence was employed as mode indicator.

Study III investigated whether the modes could be distinguished on the basis of converging evidence from introspective mode reports, event-related potentials, and response times. Are those measures congruent? Do they indicate a transition in mode?

Study IV tested whether introspective mode reports and realism of confidence are congruent mode indicators.

Method

Experimental paradigm

The experimental paradigm involved simulated two-dimensional collisions between two circular objects. In most experiments, participants' task was to indicate which of the objects was the heaviest in each trial. This paradigm is useful for studying the modes of apprehension for several reasons: First, the collisions resemble naturally occurring events because the movement patterns (kinematics) were generated to specify distal sources (dynamics), as granted by the laws of physics (cf. Stoffregen, 1993, on "natural" displays). This is different from paradigms in which such constraints are broken (e.g., Twardy & Bingham, 1999), and tasks with more artificial or unrepresentative stimulus materials. Thus, with the collision displays, observers would presumably not experience perceptual anomalies, and there is potential for KSD-based perception of relative mass. Second, the kinematic properties of the collisions are possible to exactly quantify, which may be harder to do in other "natural" paradigms as for instance in tasks using human point-light displays (e.g., Runeson & Frykholm, 1983). Third, the collisions contain several candidate kinematic variables that observers may use for their judgments. Fourth, presumably the task is new to the observers. Thus, in the course of practice, skill acquisition and possible accompanying mode transitions could be examined.

Candidate informational variables

Figure 1 shows a graphic velocity-vector description of a collision event. During the whole event, both objects project constant, but different, speeds (S_A and S_B) along the sweep axis. At the moment of collision, the objects' motions change along the collision axis (w_A and w_B). The ratio $|w_A| / |w_B|$ is proportional to the ratio of the objects' masses, m_B / m_A . This *mass ratio invariant* thus specifies the relative mass, and is an example of KSD-based information (Runeson, 1977/1983; Runeson & Frykholm, 1983).

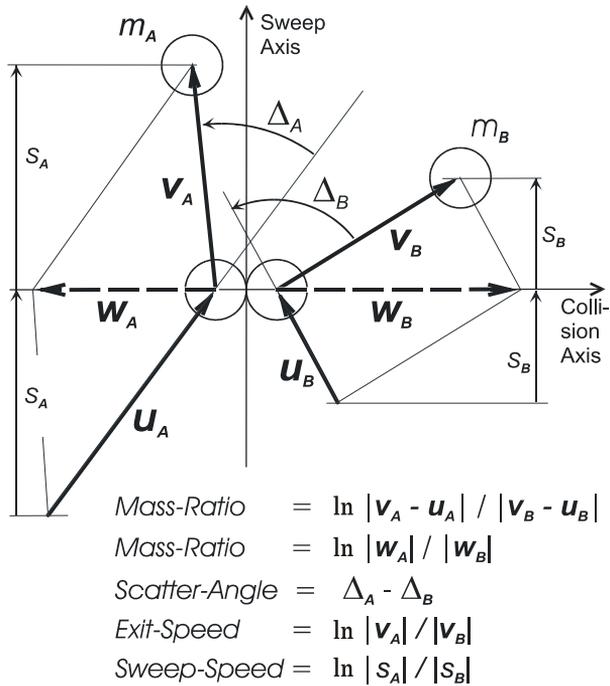


Figure 1. Velocity-vector description of a collision.

From Runeson, S., & Andersson, I. E. K. (2007). Achievement of specificational information usage with true and false feedback in learning a visual relative-mass discrimination task. *Journal of Experimental Psychology: Human Perception and Performance*, 33, 163–182. Reprinted by permission of the publisher. No further reproduction or distribution is permitted without written permission from the American Psychological Association.

The collisions also contain kinematic variables that do not specify the relative mass. The nonspecifying variables that were considered in the studies were the *Exit-Speed variable* (the ratio of the exit speeds, $|v'_A| / |v'_B|$), the *Sweep-Speed variable* (the ratio of the sweep speeds, $|S_A| / |S_B|$), and the *Scatter-Angle variable* (the difference in scatter angles, $\Delta_A - \Delta_B$). According to Gilden and Proffitt's (1989, 1994) cue-heuristic model, the mass ratio invariant is not available for perceptual pick up. Instead, observers would only pick up relative exit speeds or differences in scatter angles in order to judge the relative mass. The relative exit speed would be used according to the rule that *the object that moves the faster after impact is the lighter*. The difference in scatter angles would be used according to the rule that *the object that changes direction more is the lighter*. In the studies in this thesis, the Exit-Speed and Scatter-Angle variables are taken to be used according to those rules. The Sweep-Speed variable is taken to be used as if *the overall faster object is the lighter*. Consequently, for assessing variable usage, and

when scoring performance against the nonspecifying variables (Study II), responses were coded as correct when the respective rules were followed.

Depending on the specific set of collisions, the Exit-Speed and Scatter-Angle variables were more or less correlated with mass ratio, but always lower for Exit-Speed. For the sets of collisions in Study I, II, IV:1, and 2, Pearson product-moment correlation was .15 for Exit-Speed, and .54 for Scatter-Angle.⁶ The Sweep-Speed variable had zero correlation with mass ratio; it was included in Study I as a “nonsense” variable. In Study III, Scatter-Angle was nullified in test blocks (the objects changed direction to the same extent), but it was available in practice blocks, with .71 correlation with mass ratio. Exit-Speed had .48 correlation with mass ratio in test blocks, and .32 in practice blocks. As an example of a set of collisions, Figure 2 shows a graphic vector description of the test block collisions in Study III.

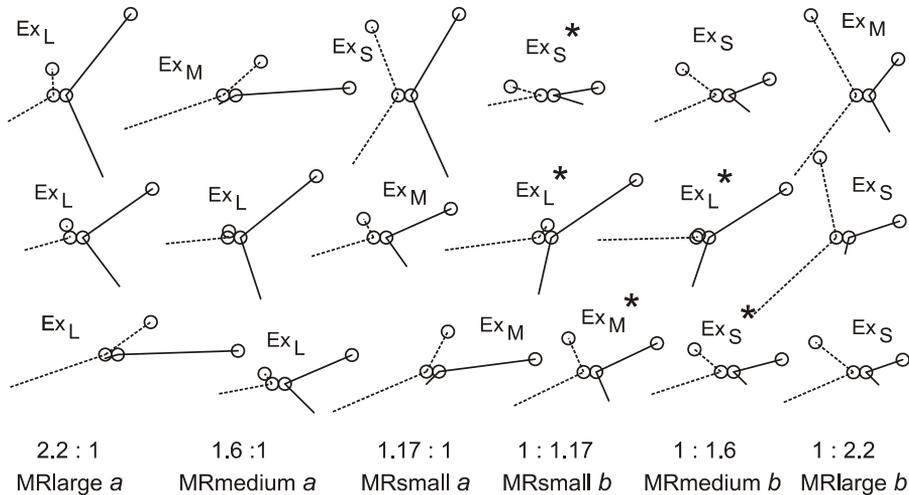


Figure 2. Test-block collisions in Study III. Each column contains collisions with the same mass ratio, with mass ratios given below. Ex_L indicate large exit speed ratios, Ex_M medium, and Ex_S small exit speed ratios.

⁶ Correlations presented in Study I (p. 167) were obtained through regression analysis with a no-constant model. The Exit-Speed correlation value was lower in that calculation as compared to the correlation values presented here, and in Study II and IV. However, the sets of collisions were identical in the studies, and the respective correlations are merely alternative ways of describing the stimulus material. The ways of calculating the correlations do not affect the results and conclusions.

Equipment and simulations

Two-object collisions were simulated and displayed by means of an in-house analog computer system. Analog computation represents variables by continuous voltages instead of numbers, thus providing smooth movements. The collisions were rendered on a high-intensity CRT monitor oscilloscope screen and back-projected onto a circular ground-glass screen, which in turn was viewed by the participants through a collimator lens system (for details about the equipment see Runeson et al., 2000; Runeson & Vedeler, 1993).

The two objects simultaneously started to move towards each other, from various off-center positions. The motions started with smooth accelerations (*natural starts*, Runeson, 1974), thus there was no artifactual suddenness of the starting motions. The objects had different driving forces, yielding different incoming speeds. After 1.5 seconds they collided near the center of the screen. The impact phase, which lasted about 100 ms, was simulated with internal dynamics, leading to a brief compression of the objects in the collision dimension. After the impact phase, the objects moved along their new trajectories for 1- 3 seconds before disappearing beyond the screen or until shut off. The objects were recognized by a continuous and a broken outline, respectively, which were randomly assigned in each trial. The collisions were presented in one of 24 orientations, randomly assigned in each trial.

A digital computer controlled the experimental variables, feedback, and response recording. In Study III, an additional system was used for EEG recordings. For indicating which object was the heaviest, there were two buttons beneath the screen. One button had a serrated raised edge, the other a smooth raised edge, corresponding to the outlines of the objects. For confidence ratings (Study II and IV), there was a display beneath the screen showing a 40-steps confidence scale, ranging from 50 % (meaning "I am purely guessing") to 100 % ("I am absolutely sure"). Participants turned a knob to adjust a marker on the scale to indicate their confidence. At the beginning of each trial, the marker was placed at random positions on the scale. For mode reports (Study III and IV), the endpoints of the scale represented SAW and INFERRED, respectively, and the knob was turned until either SAW or INFERRED was read beneath the scale.

Tentative indicators of mode of apprehension

One aim of the thesis was to explore possible methods for empirical distinction of the modes of apprehension. Several tentative mode indicators were used: variable usage, realism of confidence (cf. Runeson et al., 2000), phenomenological mode reports (cf. Kreegipuu & Runeson, 1999, 2000), event-related potentials, and response times.

Variable usage

Participants' variable usage was assessed over blocks of trials. For each participant and block, performance was fitted to each of the candidate variables (Mass-Ratio, Exit-Speed, Scatter-Angle, and in Study I also Sweep-Speed) by means of regression analyses with a no-constant PROBIT model. As goodness-of-fit measure, McFadden's R^2 (Amemiya, 1981; referred to below as R^2_{MF}) was used. Unlike ordinary R^2 measures, the R^2_{MF} indicates the fit of frequency data to a step function. With a no-constant model, the R^2_{MF} values capture the relative absence of both unsystematic (noise) and systematic (biases) errors (for details and discussion of the method, see Runeson et al., 2000).

Runeson et al. (2000) did, in line with Gilden and Proffitt (1989, 1994), regard the nonspecifying variables as cues that are used inferentially, and not as variables that are used directly in a perceptual mode. Thus, according to Runeson et al., usage of nonspecifying variables would indicate inferential functioning. This has been questioned for instance by Withagen (2004; see also Hajnal, Grocki, Jacobs, Zaal, and Michaels, 2006; Jacobs, Michaels, Zaal, & Runeson, 2001; Michaels & de Vries, 1998), who argues that nonspecifying variables are used directly, and not for inferences.⁷ The approach taken in this thesis is the same as Withagen's. It is acknowledged that nonspecifying variables might be picked up without being accompanied by supplementary inferential rules. This could occur for instance in the case of an unadapted perceptual system (see section above: Perceptual errors and nonspecifying variables). Hence, usage of nonspecifying variables is not taken to indicate inferential functioning.

On the other hand, tentatively, usage of the specifying variable is taken to indicate perceptual functioning. As shown in Figure 1, the ratio of two velocity-change vectors specifies relative mass, and this ratio is presumably available for perceptual pick up. However, the relative mass can also be derived from an assemblage of incoming and outgoing speeds, in combination with direction changes. Hence, in principle observers could pick up those cues, combine them inferentially, and performance would still fit an invariant model. According to Runeson et al. (2000), such an explanation would be unparsimonious as compared to the single-step pick up of the invariant. Moreover, analytically complex variables, such as the mass ratio invariant, are often more useful for the perceptual system than analytically simple variables, and are likely to be picked up when available (Runeson, 1977, 1994).

⁷ However, the inferences that Withagen (2004) refers to are unconscious inferences that result in a representation, as in the indirect notions of perception (see above). As defined in this thesis, the inferences in the inferential mode would not be such unconscious inferences, but instead deliberately, or consciously, used rules. In this perspective, the criticism from Withagen (that usage of nonspecifying variables is not related to inferential processes) is misdirected.

Following these arguments, performance characterized by usage of the mass ratio invariant indicates perceptual functioning (this is further discussed in Discussion: Realism of confidence).

In sum, performance characteristics may reveal whether observers use specifying or nonspecifying variables. But variable usage, in turn, only provides at most a one-way differentiation of the modes. Nonspecifying variables might be used either in the inferential mode, as was assumed by Runeson et al. (2000), or in the perceptual mode, as was argued above, thus usage of nonspecifying variables does not indicate mode.⁸ However, as argued by Runeson et al., usage of the mass ratio invariant indicates perceptual-mode functioning.

Realism of confidence

Realism of confidence concerns people's trust in their judgments. It is measured as the difference between the mean of participants' confidence in their judgments (typically given as a percentage) and their actual percentage correct judgments. If the difference is positive, participants are *overconfident*, if it is negative, they are *underconfident*.

In research on uncertainty in judgments, some have found that in cognitive tasks, such as general knowledge tasks or problem-solving tasks, people are overconfident (e.g., McClelland & Bolger, 1994; Yates, 1990). Others have found that people are well calibrated in such tasks, providing that test items are representative of the natural environment (e.g., Gigerenzer, Hoffrage, & Kleinbölting, 1991; Juslin, 1994). For sensory discrimination tasks, such as in discrimination of line lengths, there are findings of underconfidence (Björkman, Juslin & Winman, 1993; Juslin & Olsson, 1997; Juslin, Olsson & Winman, 1998; Olsson & Winman, 1996; Stankov, 1998), good calibration (e.g., Baranski & Petrusic, 1994, 1999), and even overconfidence (Kvidera & Koutstaal, 2008).

Some researchers argue that participants' judgment confidence in cognitive and sensory tasks originates in the same type of process, and that there is no systematic difference in over/underconfidence between those tasks (Baranski & Petrusic, 1994, 1999; Ferrell, 1995; Suantak, Bolger, & Ferrell, 1996). Others, however, argue that confidence in cognitive and sensory tasks originates in different sources of uncertainty (Björkman et al., 1993; Juslin, Olsson, & Winman, 1998; Olsson & Winman, 1996). According to Juslin and Olsson's (1997) sensory sampling model, in binary sensory tasks, confidence ratings are based on the experienced variability in a sample of impressions. The judgments, however, are based on a statistical aggregate (the central tendency in the sample). Judgments would then on average be more ac-

⁸ Hence, the error profile (Brunswik, 1956, 1966; see Introduction: Mode transition: a shift from "thinking to "perceiving") would not indicate mode.

curate than suggested by the confidence ratings, which would result in underconfidence. In cognitive tasks, in contrast, confidence ratings would reflect the apparent validity of used cues: When people have appropriate knowledge of the cue validities, and with representative samples of test items, good calibration is predicted (Gigerenzer et al., 1991; Juslin, 1994).

Based on Juslin and Olsson's (1997; Juslin, Olsson, & Winman, 1998) idea that there are different sources of uncertainty in the two types of tasks, and that over/underconfidence levels thus would differ between the tasks, Runeson et al. (2000) reasoned that realism of confidence could be used as an indicator of participants' mode of apprehension. That is, over/underconfidence levels would indicate whether participants perform a task as they would perform a cognitive or a sensory task, respectively. Underconfidence would indicate perceptual functioning, whereas overconfidence or good calibration would indicate inferential functioning. In this thesis, this idea is referred to as the *mode-confidence hypothesis*.

Also mode transitions would be reflected in over/underconfidence levels. If observers change from relying on cues and inferences, to relying on a perceptual impression of the sought-after-property, then they would change from being overconfident or well calibrated, to being underconfident. Runeson et al. (2000) found that novice observers were well calibrated (0 % over/underconfidence with 80 % correct judgments), whereas after practice with feedback they were underconfident (-11 % underconfidence with 88 % correct). This result, together with the finding of a shift in variable usage from the Exit-Speed variable to the mass ratio invariant, suggested that a mode shift had occurred during practice.

What complicates such an interpretation of over/underconfidence levels is that easy tasks (tasks that yield a large proportion correct) tend to generate underconfidence, whereas difficult tasks (tasks that yield a small proportion correct) tend to generate overconfidence, at least in cognitive tasks: the *hard-easy effect* (Lichtenstein & Fischhoff, 1977). According to Juslin et al. (1998), in sensory tasks there is a disposition towards underconfidence at most difficulty levels (but for a contrary view see for example Baranski & Petrusic, 1999), but the hard-easy effect will still influence the over/underconfidence scores. The hard-easy effect seems to stem from methodological artifacts such as confidence-scale end effects and regression effects, and, at least in cognitive tasks, it is considered neutral at 75 % correct (Erev, Wallsten, Budescu, 1994; Juslin, Winman, & Olsson, 2000; Suantak, Bolger, & Ferrell, 1996). In Runeson et al. (2000), proportion correct increased from pre- to posttest, which led to reduced over/underconfidence scores due to the hard-easy effect. However, when comparing over/underconfidence scores for subsets of collisions with similar proportions correct, over/underconfidence scores were still lower in the posttest. This showed that the overall lower over/underconfidence score in the posttest was not due only to a hard-easy effect, and that there was a true differ-

ence in over/underconfidence level, which strengthens the conclusion that a mode transition had occurred.

Hajnal et al. (2006) criticized Runeson et al's (2000) conclusion, claiming that the difference in over/underconfidence scores emerged because participants used different variables before and after practice. Before practice, when the participants were using a nonspecifying variable, proportion correct was smaller than after practice when they had changed to using the mass ratio invariant. Since over/underconfidence is calculated as the difference between the mean of the confidence ratings and the proportion of correct judgments, the smaller proportion correct before practice would lead to an elevated over/underconfidence score. Hence, if participants were using nonspecifying variables in the perceptual mode, good calibration could still appear due to a mismatch between the experimenters' criterion of performance, and the variable actually used.

In Study II, individuals' variable usage was assessed block-wise, by their R^2_{MF} values for each candidate variable. Both performance and over/underconfidence were individually scored against the most used variable in each block, a procedure suggested by Hajnal et al. (2006). As was argued in Study II, this procedure would disclose possible underconfidence for usage of nonspecifying variables, which in turn would reveal whether nonspecifying variables were used in the inferential or the perceptual mode. To counteract the hard-easy effect, main comparisons in Study II, and also in Study IV, were made on subsets of collisions that yielded around 75 % correct, or between subsets of collisions with similar proportion correct.

Phenomenological mode reports

In Study III, IV:1 and 2, phenomenological mode reports were collected. After each mass ratio judgment, participants indicated what mode they were functioning in; whether they "SAW" or "INFERRED" the relative mass. Unlike over/underconfidence scores, which are based on aggregated data, this method would, if successful, capture trial-by-trial mode shifts.

Kreegipuu and Runeson (2000; see also Kreegipuu & Runeson, 1999) collected similar mode reports. Performance in the relative mass discrimination task improved after practice, and the proportion of SAW trials increased from 53 % to 65 %. It was concluded that it was "higher incidence" of perceptual-mode functioning after practice. Moreover, most obvious in the post-test, the proportion of SAW trials was largest for the largest mass ratios, and smallest for mass ratios near unity. Such distribution of SAW responses was expected because large mass ratios are presumably easier to discriminate than small ratios. If small mass ratios are harder to discriminate, possibly such cases would evoke cue-based judgments and thus being performed in the inferential mode (Runeson et al., 2000).

Interpretation of introspective data is not unproblematic however. A fundamental question is whether the phenomena asked about are introspectively available. Nisbett and Wilson (1977) claimed that reports about higher cognitive processes are largely invalid because people do not have introspective access to such processes. Instead, introspective reports would be based on participants' "a priori theories about the causal connection between stimuli and response" (p. 233). However, unlike the cognitive processes per se, the products of those processes would be available to introspection. Nisbett and Wilson's proposal has been criticized on several grounds, as for instance how to distinguish process from product (e.g., Ericsson & Simon, 1980; White, 1988). Moreover, as demonstrated by Kellogg (1982), if cognitive processes are explicit, or consciously controlled, they may be available to introspection, in contrast to unconscious automatic processes (cf. Ericsson & Simon, 1980, p. 225). Wilson (2002) concluded that when responses are caused by the "conscious self", instead of the "adaptive unconscious", people do have at least some introspective access to the processes leading to the responses.

Would it be possible to report on the modes of apprehension in the relative mass discrimination task? Perceptual-mode functioning is assumed to be phenomenologically characterized by a perceptual impression of the relative mass. Inferential mode functioning, in contrast, is assumed to be characterized by a search for, or identification of, cue variables, as for instance the objects' relative speed, and by the consciously controlled use of heuristic rules. Thus, participants were asked to introspect and report on the occurrence or nonoccurrence of a specific perceptual impression, together with the occurrence or nonoccurrence of explicit application of rules. If these characterizations of mode functioning hold, reasonably valid mode reports may be achievable.

When participants are offered fixed alternatives, such as SAW and INFERRED, for reporting on their mental processes or experiences, it is essential that those alternatives fit to the actual processes and experiential phenomena that occur (cf. Ericsson & Simon, 1980; Jack & Shallice, 2001; White, 1980). In Study III, participants were instructed to indicate SAW if they "directly saw" or "felt" which object was the heavier, if they used "a feeling" or "intuition", if they "did not know why they had an impression that the object was heavier", and if they "after perceiving the relative mass was pondering over why, or tried to rationally explain why". They were instructed to indicate INFERRED if they were "figuring out" which object was the heavier, or if they "attended to a part of the movement pattern and then used some rule for judging the relative mass". In Study IV, the description of the perceptual mode was changed to the phrase "If you had an impression, directly saw, or felt that one of the objects was heavier". The phrases "a feeling" and "intuition" were omitted. As argued in Study IV, such phrases might be ambiguous and unclear. However, it is important to note that there were no independent means to verify that the descriptions of the modes in

either study indeed would fit to the experiential phenomena that would occur in the respective mode.

Introspective evidence is strengthened when combined with evidence from behavioral and psychophysiological data (Jack & Roepstorff, 2002). Combining several types of data would provide a way to "triangulate" on the studied phenomena (for examples of this approach see Lutz, Lachaux, Martinerie, & Varela, 2002; Summerfield, Jack, & Burgess, 2002). In an attempt to do such triangulation, relations between the mode reports and magnitudes of mass ratios and exit speed ratios, variable usage, and response times were examined in Studies III and IV. In Study VI, the mode reports were also related to participants' over/underconfidence levels. Furthermore, in Study III, the mode reports were related to event-related potentials elicited during the collisions.

Event-related potentials and response times

In Study III, participants' electroencephalogram (EEG) was recorded from six scalp sites located at the frontal, the parietal, and the occipital lobes. EEG is obtained by registering changes in voltages in the cortex by electrodes placed on the scalp. EEG time resolution is high, providing possibilities to follow rapid changes in neural processes, and, presumably, changes in states or cognitive functioning (e.g., Rugg & Coles, 1995). Amplitude of the event-related potential (ERP) was measured. ERPs consist of the EEG signals averaged over a number of trials. The signals are time-locked to stimulus events, thus only signals related to the events are retained and noise originating from other brain activities or from outside the brain is cancelled out. The collisions were displayed with a constant time from appearance of the objects, to start of approach movements, and to the collision moment. The ERPs were time-locked to these events.

Typically, a stimulus event that is relevant to a given task (i.e., target information) elicits a slow positive deflection in the ERP, which peaks around 400 - 800 ms after the onset of the event, with maximum amplitude at centro/parietal sites: a P3b component (e.g., Fabiani, Gratton, Karis, & Donchin, 1987). In the relative mass discrimination task, the relative velocity change during the collision moment is the target information because the change provides information about which object is the heavier. Therefore, analyses were made with the ERPs averaged over a window 400 - 800 ms after the collision moment.

Several task conditions influence the amplitude of the P3b component (for reviews see Kok, 2001; Pritchard, 1981). For example, amplitude increases with stimulus relevance (e.g., Johnson, 1988) and with high stimulus discriminability, providing that stimuli are relevant and attended to (e.g., Comerchero & Polich, 1999; Polich, 1987). In contrast, amplitude is reduced when stimuli are degraded (e.g., Magliero et al., 1984; Kok, 1986) and in

tasks that require additional cognitive processing (Verleger, 1988). For example, when accuracy is stressed (Begleiter et al., 1983; Pfefferbaum et al., 1983), in visual search tasks when initial memory sets contain more elements (Brookhuis et al., 1981, Okita et al., 1985), in mental rotation tasks (Wijers et al., 1989), and when varied stimulus-response mapping is required instead of consistent mapping (Kramer, Schneider, Fisk, & Donchin, 1986), amplitude of P3b is reduced.

Most models of ERP component generation assume that components are manifestations or reflections of information processing stages that occur between stimulus onset and response (e.g., Rugg & Coles, 1995). According to the "context-updating" hypothesis (Donchin, 1981; Donchin & Coles, 1988), the P3b component reflects revision, or updating, of working-memory representations of the environment when relevant stimuli are encountered. According to the "context-closure" hypothesis (Verleger, 1988), P3b reflects the release of excess activation from perceptual control areas when "contexts" are completed. Subjects then maintain an internal template of the context together with an expectancy of the closing event.

Diverging from such information processing interpretations, and thus more relevant to the present thesis, Kotchoubey (2002, 2006) presented an information extraction model of ERP component generation. In that model, ERP components reflect feedforward and feedback stages of sensorimotor cycles. Negative ERP deflections reflect feedforward anticipation of relevant (target) stimuli, in which preparatory states build up in specific cortical networks. When information that corresponds to prepared activation is picked up from the environment, activation is "consumed", and positive ERP deflections, such as the P3b, appear (Kotchoubey, 2006). Kotchoubey (2002) concluded that ERP deflections reflect the effects of stimulus variables, and not putative mental operations. "Whenever the two kinds of independent variables (i.e., internal cognitive processes versus external environment) can be separated, a big part (if not the whole) of the ERP effects usually attributed to cognitive mediation, such as memory or expectation, can be described as a function of environmental information" (p. 45).

Adopting Kotchoubey's (2002, 2006) approach that positive deflections are related to target information extraction, it is assumed that perceptual-mode functioning, which is characterized by extraction of task relevant information, is related to large positive deflections (such as P3b). Inferential functioning, in contrast, is characterized by conscious elaboration of cue variables. In such case, P3b amplitude would be reduced due to less target information extraction, perhaps together with a reduction due to the additional cognitive processing that is required (Verleger, 1988). In Study III, P3b amplitudes for SAW and INFERRED trials were compared. If P3b amplitudes were larger in SAW trials than in INFERRED trials, possibly it would support the validity of the mode reports.

In Study III, IV:1 and 2, response times were also recorded, defined from the moment of collision to the press of the response button. Although participants were not informed about this, nor required to respond quickly, also response times may provide an indication of mode functioning and provide a support for the validity of the mode reports. The perceptual mode entails only the pick-up of an informational variable. The inferential mode, in contrast, entails not only pick-up of one, or more, informational variables, but also choice and application of rules, which might prolong the response times (this is further discussed in Discussion: Response times). Kreegipuu and Runeson (2000) found that response times were longer in INFERRED than in SAW trials, in both pre- and posttests. This was taken as support for the validity of the mode reports: "It may indicate that observers, while reporting themselves performing in the 'INFERRED' mode, were really engaged in some extra mental activity" (p. 14).

Empirical studies

In this section, specific aims, methods, and results of the studies are summarized. Results are interpreted and discussed in the Discussion section. Note that Study I and II are based on the same experiment. Study I concerned variable usage and the effects of false feedback, whereas Study II concerned modes of apprehension.

Study I

In a task showing a stick-figure pulling a handle, Michaels and de Vries (1998) trained participants, without instructions, as to what to judge by using feedback in accordance with different informational variables in the kinematic patterns. They found that participants conformed to feedback, and concluded that what variables are exploited depends on the feedback. One purpose of Study I was to test the effect of "true" versus "false" feedback on variable usage in the collision relative mass task. When feedback was false, it was based on cue variables with limited informational value. Participants were instructed to judge which object was the heavier, but would feedback determine what variable judgments were based on?

In a version of the relative mass task that required quantitative judgments (Jacobs, Michaels, & Runeson, 2000; see also Jacobs, Runeson, & Michaels, 2001) it was found that linear combinations of the Scatter-Angle and Exit-Speed variables explained performance better than the mass ratio invariant variable, at least for some individuals. A second purpose of Study I was to examine whether participants rely on such combinations also in the binary version of the task.

Participants

Thirty undergraduate students and 10 staff members from the Department of Psychology, 22 women and 18 men, participated. The first 20 were randomly assigned to one of four feedback conditions. To improve matching of the groups, the remaining 20 were assigned on the basis of their pretest scores.

Design and Procedure

Sixty-four different collisions were shown, in blocks with randomly permuted presentation order: a pretest block (64 trials), four blocks with feedback (256 trials), and a posttest block (64 trials). In each trial, participants indicated which object was the heavier. (They also rated their confidence, see Study II.) There were four feedback conditions. In the Mass-Ratio condition, feedback was given according to the actual correctness of responses. In the Scatter-Angle, Exit-Speed, and Sweep-Speed false-feedback conditions, feedback reflected the accordance of the responses with the respective variables.

Results

Group-level variable usage

Fits of individuals' block-wise performance to the candidate variables were tested by means of PROBIT analyses (see Method: Variable usage). Within each feedback group, R^2_{MF} correlations for each candidate variable were averaged over participants. For all groups, the Exit-Speed variable reached the best fit in the pretest, whereas during practice, all groups gravitated towards the variable they got feedback on (see Figure 3). The Exit-Speed group became highly consistent in reliance on Exit-Speed. Thus, considered as groups, participants learned to use the feedback variables, whether or not correct relative to the assigned task of judging relative mass.

Individual-level variable usage

For each individual, the predominantly used variable in each block was singled out according to the R^2_{MF} correlations (.15 or higher). As novices, 27 of the 40 participants predominantly used Exit-Speed, 3 Sweep-Speed, and 5 Mass-Ratio. After practice, all 10 in the Exit-Speed group used Exit-Speed, and 7 of the 10 participants in the Mass-Ratio group used Mass-Ratio. In the Scatter-Angle group, 6 used Scatter-Angle, and in the Sweep-Speed group 5 used Sweep-Speed. In both Scatter-Angle and Sweep-Speed groups, two participants resisted the false feedback and used Mass-ratio after practice, showing exceptions from feedback dependency.

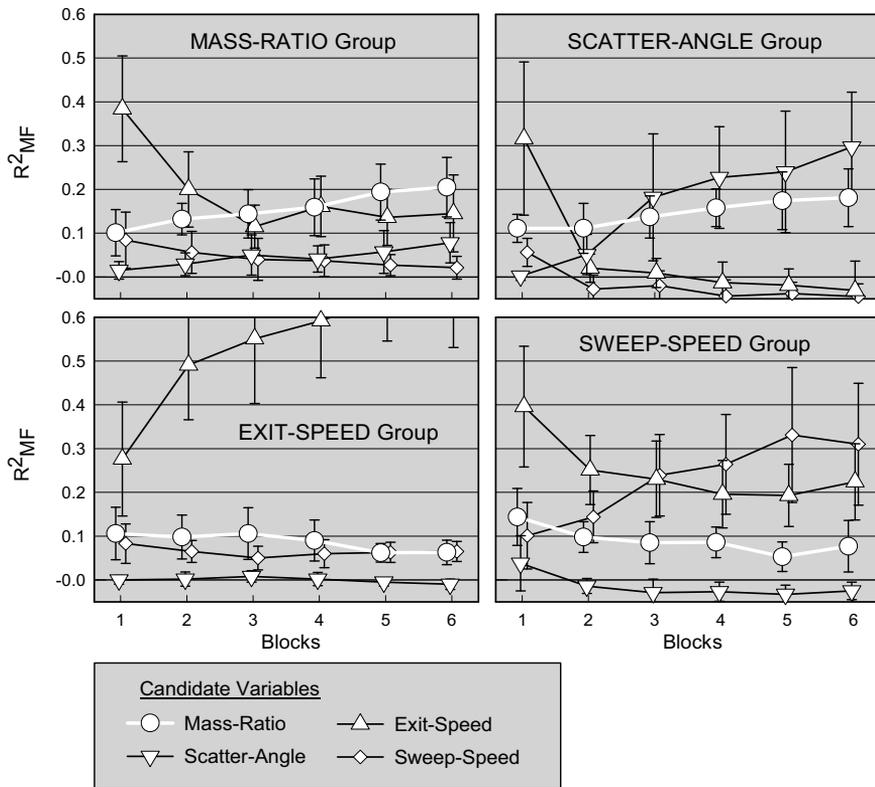


Figure 3. Group-level PROBIT correlation results for pretest, four practice blocks, and posttest, for each feedback group. Error bars show 95 % between-participants confidence intervals.

From Runeson, S., & Andersson, I. E. K. (2007). Achievement of specificational information usage with true and false feedback in learning a visual relative-mass discrimination task. *Journal of Experimental Psychology: Human Perception and Performance*, 33, 163–182. Reprinted by permission of the publisher. No further reproduction or distribution is permitted without written permission from the American Psychological Association.

Post hoc weighted linear combinations of Exit-Speed and Scatter-Angle were also considered. The relative weights of the variables were determined, for each individual's performance in each block, to obtain the highest correlation possible. In cases when Exit-Speed or Scatter-Angle alone did not supersede the fit of Mass-Ratio, the combination of Exit-Speed and Scatter-Angle rarely superseded the fit of Mass-Ratio. Only for one participant (in the Mass-Ratio feedback group), did the combination best explain performance, but only in two of the blocks (see Figure 4, participant Mass/2).

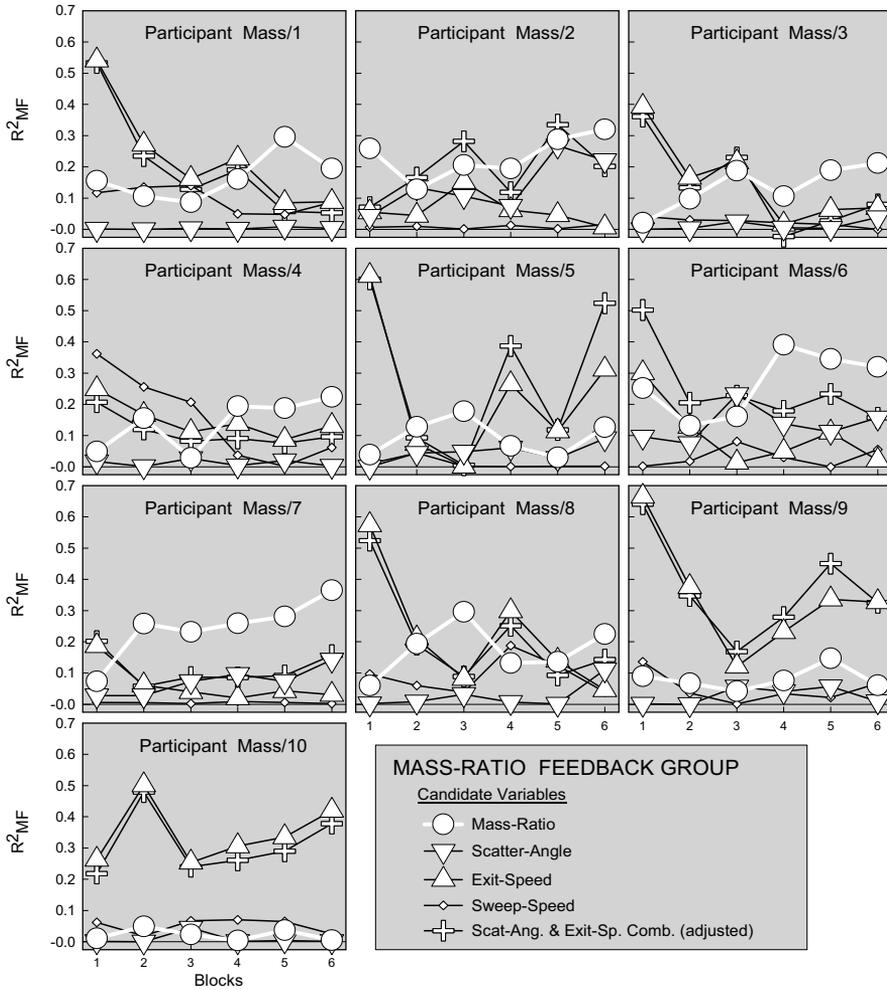


Figure 4. Mass-Ratio feedback group individual R^2_{MF} correlations, for each candidate variable, and for post hoc linear combinations of Exit-Speed and Scatter-Angle variables (adjusted to incorporate a correction for an extra parameter, see p. 169-171 in article).

From Runeson, S., & Andersson, I. E. K. (2007). Achievement of specificational information usage with true and false feedback in learning a visual relative-mass discrimination task. *Journal of Experimental Psychology: Human Perception and Performance*, 33, 163–182. Reprinted by permission of the publisher. No further reproduction or distribution is permitted without written permission from the American Psychological Association.

In sum, in all groups novices predominantly used the Exit-Speed variable. All participants in the Exit-Speed feedback group continued to rely on Exit-Speed, whereas in the Scatter-Angle and the Sweep-Speed groups there were exceptions from plain feedback dependency. Contrary to the quantitative

version of the task (Jacobs et al., 2000; Jacobs, Runeson, & Michaels, 2001), post hoc linear combinations of Exit-Speed and Scatter-Angle rarely superseded the fit of Mass-Ratio.

Study II

As shown in Study I, most novices predominantly relied on nonspecifying variables, in particular the Exit-Speed variable. One purpose of Study II was to test whether nonspecifying variables were used in the inferential or the perceptual mode, as would be indicated by participants' realism of confidence. Overconfidence or good calibration would indicate inferential functioning, whereas underconfidence would indicate perceptual functioning. Individuals' judgments were block-wise fitted to the candidate variables, and over/underconfidence was scored against the respective best fitting variable (Hajnal et al., 2006). By this procedure, inflated over/underconfidence resulting from mis-scoring of performance was counteracted, and possible underconfidence for usage of nonspecifying variables could thus be revealed (see Introduction: Realism of confidence).

A second purpose was to examine whether one and the same variable would change from being used inferentially to being used in the perceptual mode during practice. Hence, a group of participants received feedback that encouraged use of the Exit-Speed variable (i.e., the Exit-Speed group in Study I), although the task remained to judge which object was heavier. As suggested by the special feedback, in this condition it would appear to be a one-to-one relation between the Exit-Speed variable and relative mass. Assuming that novice participants use the exit speed relation inferentially (i. e., as a cue), there is the possibility that they would start to use the same variable in the perceptual mode (i.e., not as a cue) during practice with the special feedback. Such a change was to be indicated by a shift from good calibration or overconfidence in the pretest, to underconfidence in the posttest.

Participants

For the pretest, all 40 participants, 18 men and 22 women, were considered as one group. For the posttest, two groups with different feedback conditions were considered. In the normal feedback group (NF), 4 men and 6 women participated. In the Exit-Speed "false"-feedback group (EF), 6 men and 4 women participated.

Design and procedure

For design and procedure, see Study I.

Results

Novice over/underconfidence

Of 40 novices, 27 predominantly used the Exit-Speed variable, 5 the mass ratio invariant, and 3 the Sweep-Speed variable, as indicated by their highest R^2_{MF} values (see Study I). Over/underconfidence was calculated for Exit-Speed users and invariant users. Invariant users were 6.5 % overconfident, with 75.9 % correct. Exit-Speed users were highly overconfident, 17.6 %, with 63.9 % correct, when scored against mass ratio, and -1.4 % underconfident, with 82.9 % correct, when performance and over/underconfidence was scored against Exit-Speed.

To avoid confounding with the hard-easy effect, subsets of collisions with midrange proportion correct was selected. For the subsets, invariant users were 9.7 % overconfident (with 70.4 % correct), whereas Exit-Speed users were 5.3 % overconfident (with 71.8 % correct) scored against Exit-Speed. The overconfidence did not differ significantly between the groups, $t(30) = .87, p = .39$.

Over/underconfidence after practice

In the normal feedback group, seven participants used the invariant after practice. In contrast to novice invariant users' overconfidence, the after-practice invariant users were -2.3 % underconfident, with 77.0 % correct, although not significantly below zero over/underconfidence, $t(6) = .71, p = .51$. The difference in over/underconfidence between pre- and posttest invariant users was approaching significance, $t(10) = 2.05, p = .07$. It can be noted that the single participant in the normal feedback group that was categorized as invariant user in both pre- and posttests was 8.3 % overconfident (76.6 % correct) in the pretest, and -3.1 % underconfident (79.7 % correct) in the posttest.

In Figure 5, over/underconfidence for each mass ratio category is plotted against correctness, for pre- and posttest invariant users. The slopes of the fitted curves illustrate the hard-easy effect. For most mass ratios, proportions correct are quite similar in pre- and posttests, and, in most cases, the posttest invariant users are about 8 % less over/underconfident than the novice invariant users.

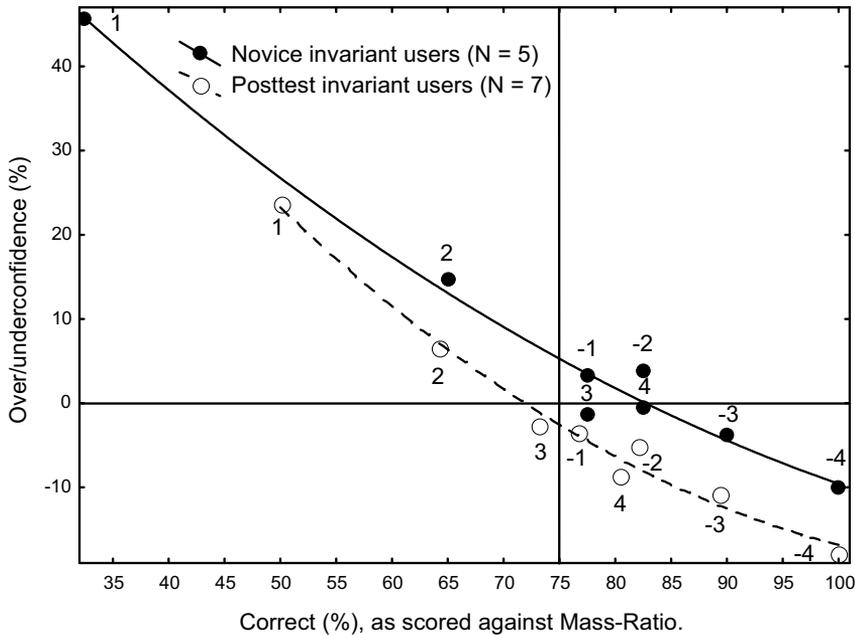


Figure 5. Over/underconfidence plotted against proportion correct for novice invariant user and invariant users after practice. The dots represent results for each mass ratio. Curves are fitted second order polynomial functions.

From Andersson, Isabell E. K. & Runeson, Sverker (2008) 'Modes of Apprehension, Realism of Confidence, and Variable-use in Visual Discrimination of Relative Mass', *Ecological Psychology*, 20:1, 1— 31. Reprinted by permission of the publisher (Taylor & Francis Ltd, <http://www.tandf.co.uk/journals>).

After-practice Exit-Speed users were quite well calibrated over the whole set of collisions. In the normal feedback group (NF), three participants used the Exit-Speed variable after practice; they were -0.7 % underconfident, with 78.1 % correct, scored against Exit-Speed. In the Exit-Speed feedback group (EF), all ten participants used Exit-Speed after practice; they were 1.8 % overconfident, with 89.7 % correct, as scored against Exit-Speed. For subsets of collisions centering on 70 % correct there were no significant differences in over/underconfidence ($p > .62$), neither between novice Exit-Speed users and the NF or EF groups, nor between the NF and EF groups.

The quite good calibration for Exit-Speed users is illustrated in Figure 6. Novices and NF Exit-Speed users had rather similar over/underconfidence scores, with good calibration at 75 % correct (where the hard-easy effect is considered neutral). However, for the EF group, mass ratios with very large proportion correct yielded only marginal underconfidence, if any at all. Thus, in contrast to all other conditions the hard-easy effect did not appear for the EF group.

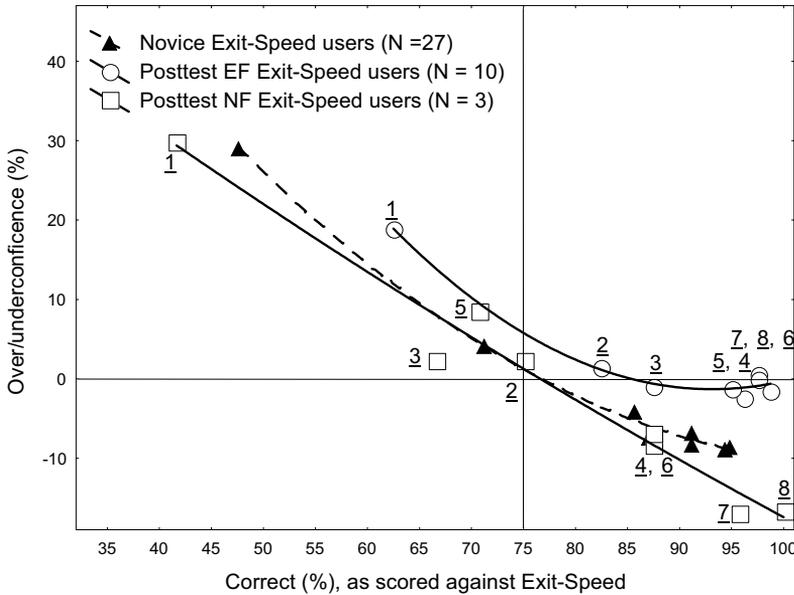


Figure 6. Over/underconfidence plotted against proportion correct for novice Exit-Speed users, for Exit-Speed users after Exit-Speed feedback, and for Exit-Speed users after normal feedback. The dots represent results for eight categories of exit speed difference. Curves are fitted second order polynomial functions.

From Andersson, Isabell E. K. & Runeson, Sverker (2008) 'Modes of Apprehension, Realism of Confidence, and Variable-use in Visual Discrimination of Relative Mass', *Ecological Psychology*, 20:1, 1— 31. Reprinted by permission of the publisher (Taylor & Francis Ltd, <http://www.tandf.co.uk/journals>).

In sum, participants categorized as invariant users were overconfident in pretest whereas in posttest they tended towards underconfidence. Although the difference was only approaching statistical significance, this suggests that a mode transition occurred to some degree for these participants. Participants categorized as Exit-Speed users were quite well calibrated both in pre- and in posttests, when correctness and over/underconfidence was scored against Exit-Speed. Exit-Speed users who received feedback based on Exit-Speed were well calibrated even for subsets of collisions with high percentage correct. This suggests that Exit-Speed users were functioning inferentially both before and after practice, in both feedback conditions.

Study III

The purpose of Study III was to investigate whether mode of apprehension could be distinguished on the basis of converging evidence from introspective mode reports, ERPs, and response times. ERPs and response times for reported mode (SAW and INFERRED) were compared. It was expected that in trials in which participants reported SAW, the P3b component (defined as mean ERP amplitude 400-800 ms after the collision moment) would be larger, and the response times would be shorter compared to trials in which they reported INFERRED (cf. Kreegipuu & Runeson, 2000), (see Introduction: Event-related potentials and response times). Moreover, reported mode was compared for different magnitudes of mass ratio and exit speed ratio in the collisions. In line with Kreegipuu and Runeson (2000), it was expected that large mass ratios would lead to relatively more SAW responses than smaller mass ratios. On the other hand, the exit speed ratios were not expected to influence reported mode.

Furthermore, reported mode was compared between a pre- and a posttest after practice with feedback. In line with Runeson et al's (2000) mode transition model, it was expected that the proportion SAW responses would increase during practice.

Participants

Nine Uppsala University undergraduate students participated, four women and five men.

Design and procedure

The experiment consisted of a pretest (180 trials), practice with feedback (384 trials), and a posttest (180 trials). In the tests, 18 different collisions were shown, presented in ten blocks. The m_B / m_A mass ratios were 1:2.2, 1:1.6, 1:1.17, 1.17:1, 1.6:1, and 2.2:1. The exit speed ratios (defined as the natural logarithm of the ratio of the objects' speeds after the moment of collision) ranged from .04 to 3.56. In the practice blocks, 64 other collisions were shown, with mass ratio range from 1:3 to 3:1. The scatter-angle cue was available in practice collisions but not in test collisions.

In test blocks, in each trial participants first indicated which object was the heaviest, and thereafter how they performed the task; SAW or INFERRED (for instructions see Method: Phenomenological mode reports). In practice blocks no mode reports were given.

ERPs were recorded from six scalp sites (F3, F4, P3, P4, O1, and O2). The averaged ERP amplitudes 400 - 800 ms after the moment of collision were analyzed. Response times were registered from the moment of collision to the response button press.

Results

Performance characteristics

In pretest, mean R^2_{MF} correlation for the Exit-Speed variable was .52 ($SD = .29$), whereas it dropped to .11 ($SD = .13$) in the posttest. Mean R^2_{MF} correlation with the mass ratio invariant was .33 ($SD = .08$) and .34 ($SD = .07$), in pre- and posttests, respectively. Among the individuals, in the pretest most participants reached higher correlation with Exit-Speed, whereas in the posttest most reached higher correlation with the mass ratio invariant, see Figure 7.

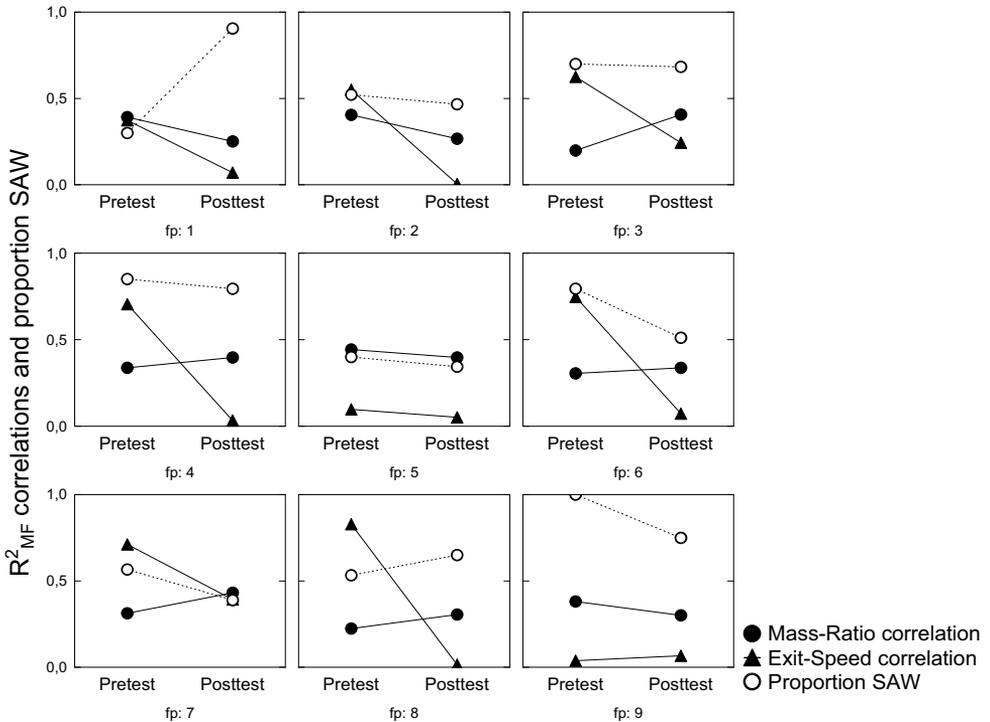


Figure 7. Individuals' R^2_{MF} correlations with the mass ratio invariant and the Exit-Speed variable, and proportions SAW, in pre- and posttests.

Mode reports

Proportion SAW responses was about the same in pre- and posttests: .63 ($SD = .22$) and .61 ($SD = .19$), respectively, $t(8) = .22$, $p = .83$. Both in pre- and posttests proportion SAW responses varied considerably among indi-

viduals (see Figure 7). Note that for one participant (S9), proportion SAW was 1.0 in pretest. Figure 7 also shows that proportion SAW was not systematically related to variable usage.

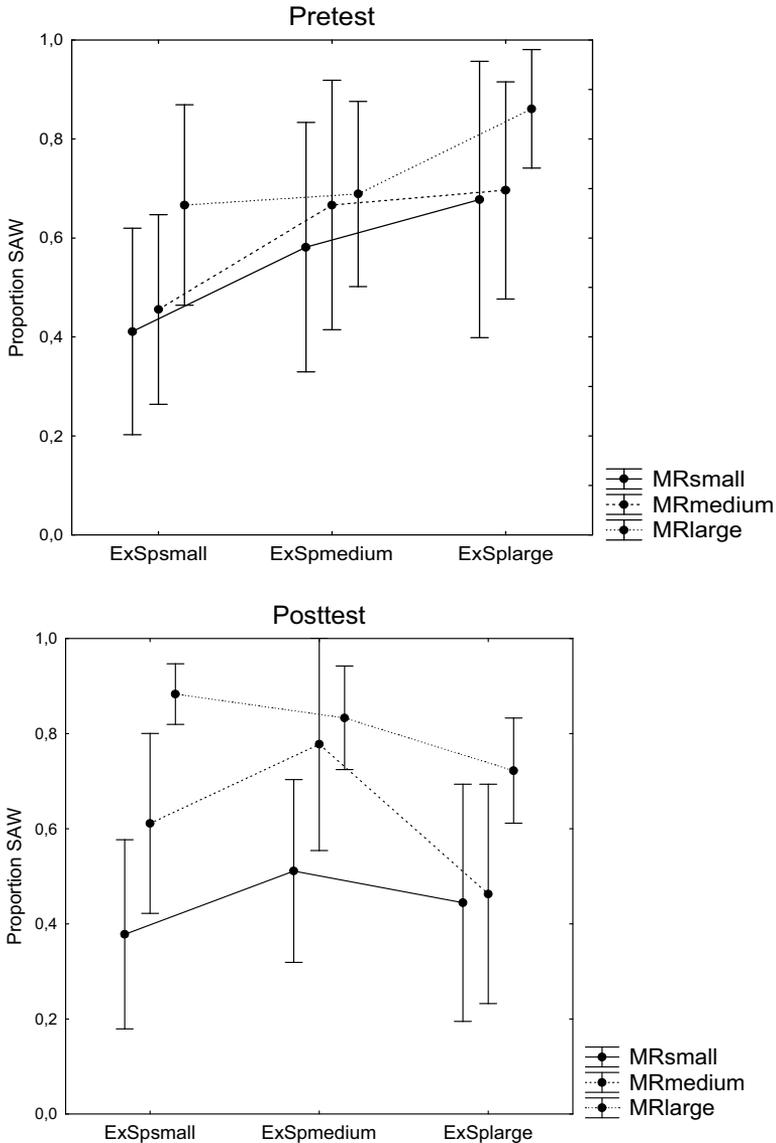


Figure 8. Proportion SAW responses in pre- and posttests, for different magnitudes of mass ratio and exit speed ratio. Errorbars indicate 95 % confidence intervals (n = 9).

The mode reports were not unsystematically given however. The magnitudes of both mass ratio (MR, three categories) and exit speed ratio (ExSp, three categories) influenced the proportion SAW. As seen in Figure 8, the proportion SAW increased with the magnitude of the mass ratio in particular in posttest, whereas proportion SAW increased with exit speed ratio in pretest. For pretest, a factorial repeated-measures ANOVA with MR (3) and ExSp (3) as factors revealed a significant main effects both of MR, $F(2, 16) = 5.54, p = .01$, and of ExSp, $F(2, 16) = 5.47, p = .01$, but no significant interaction effect, $F(4, 32) = 2.38, p = .07$. For posttest, a factorial repeated-measures ANOVA with MR (3) and ExSp (3) as factors revealed significant main effects of MR, $F(2, 16) = 24.49, p < .001$, and of ExSp, $F(2, 16) = 4.61, p = .03$, and a significant interaction effect, $F(4, 32) = 8.66, p < .001$.

Electrophysiology

Initially, for each individual, ERP traces were averaged over SAW trials and INFERRED trials separately. As an illustration, in Figure 9 grand averages over participants are shown for posttest for electrode P3. After the moment of collision (denoted 0 ms in the graph), a positive ERP deflection was elicited, most prominently over parietal electrodes (a P3b component). The amplitude of the P3b component was measured within a window enclosing 400 - 800 ms.

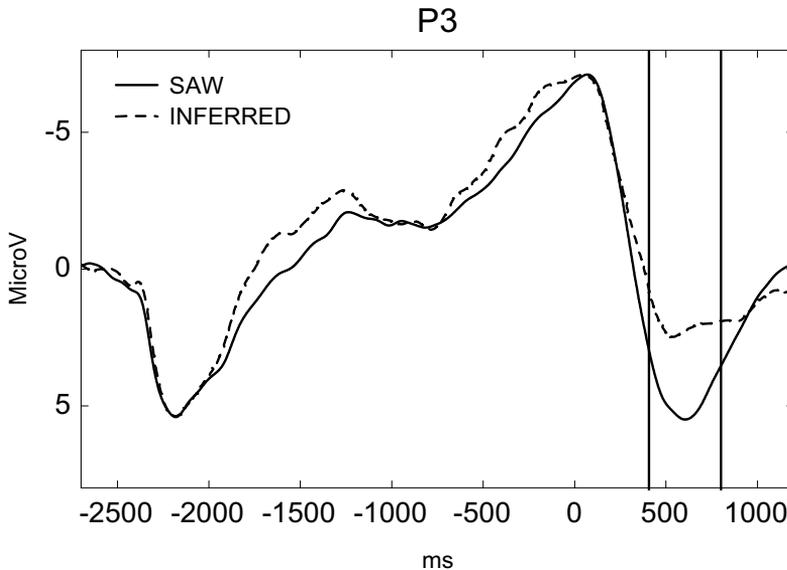


Figure 9. Posttest grand average for SAW and INFERRED trials for the P3 electrode. Marked area indicate significantly different mean amplitude within 400 - 800 ms ($p < .05, n = 9$).

As expected, mean P3b amplitude was larger in SAW than in INFERRED trials. A three-way repeated-measures ANOVA with TEST (2), MODE (2), and electrode (6) as factors revealed a main effect of MODE, $F(1, 7) = 14.13$, $p < .01$, and of electrode, $F(5, 35) = 4.96$, $p < .005$, but not of TEST, $F(1, 7) = 1.21$, $p = .31$.

Paired t-tests of mean P3b amplitude in single electrodes revealed that, in pretest, SAW trials elicited significantly larger amplitudes than INFERRED trials in electrodes P3, P4, and O1 ($p < .5$, $n = 8$). In posttest, SAW trials elicited significantly larger amplitude in electrodes F3, P3, P4, O1, and O2 ($p < .05$, $n = 9$).

The magnitudes of the mass ratios (MR) and exit speed ratios (ExSp) were both reflected in P3b amplitudes, but in different ways in pre- and posttests. In Figure 10, pre- and posttest grand averages for the P3 electrode are shown for three magnitudes of mass ratio. P3b amplitude tended to increase with the mass ratio only in posttest. A factorial repeated-measures ANOVA with TEST (2), MR (3), and electrode (6) as factors revealed no significant main effect of TEST on amplitude, $F(1, 8) = 2.02$, $p = .19$, but there were significant main effects of MR, $F(2, 16) = 4.71$, $p = .02$, and of electrode, $F(5, 40) = 7.14$, $p < .001$. There was a significant interaction effect between TEST and MR, $F(2, 16) = 4.05$, $p = .04$. Paired t-tests between MRsmall and MRlarge revealed no significant difference in any electrode in the pretest. In the posttest, there were significant differences in F3, F4, P3, and P4 ($p < .05$, $n = 9$).

Figure 11 shows grand averages for the three magnitudes of exit speed ratio. (Averages in Figures 10 and 11 are based on the same data, but trials are sorted differently.) In pretest, P3b amplitude tended to increase with exit speed ratio. A factorial repeated-measures ANOVA with TEST (2), ExSp (3), and electrode (6) as factors revealed no significant main effect of TEST, $F(1, 8) = 2.02$, $p = .19$, but there were significant main effects of ExSp, $F(2, 16) = 4.71$, $p = .02$, and of electrode, $F(5, 40) = 7.15$, $p < .001$. There was a weak significant interaction effect between TEST and ExSp, $F(2, 16) = 3.63$, $p = .05$. Paired t-tests between ExSp_{small} and ExSp_{large} indicated significant differences in P3, P4, and O1 in pretest. In the posttest, there were no significant differences ($p < .05$, $n = 9$).

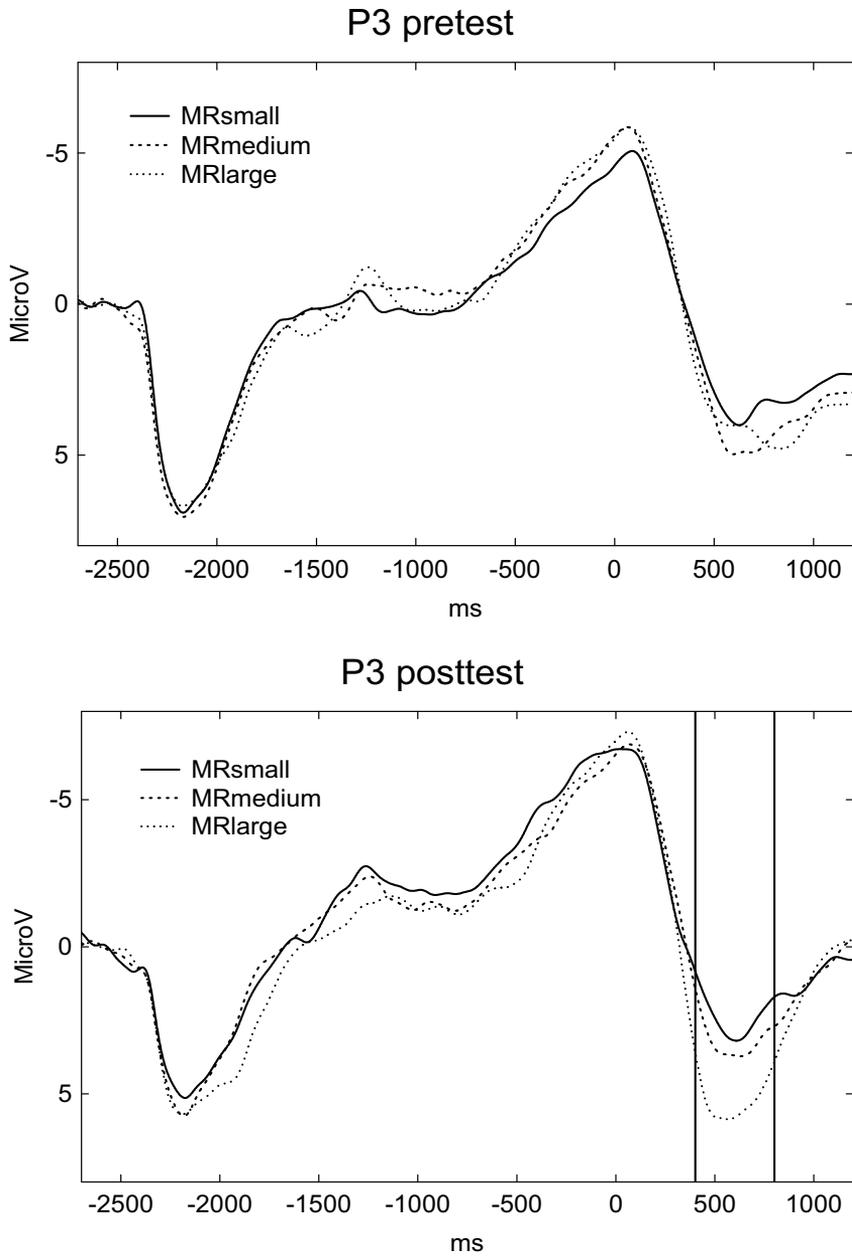


Figure 10. Pre- and posttest grand averages for the P3 electrode, with trials sorted on mass ratio. Marked area denote significant difference in amplitude between MRsmall and MRlarge ($p < .05$, $n = 9$).

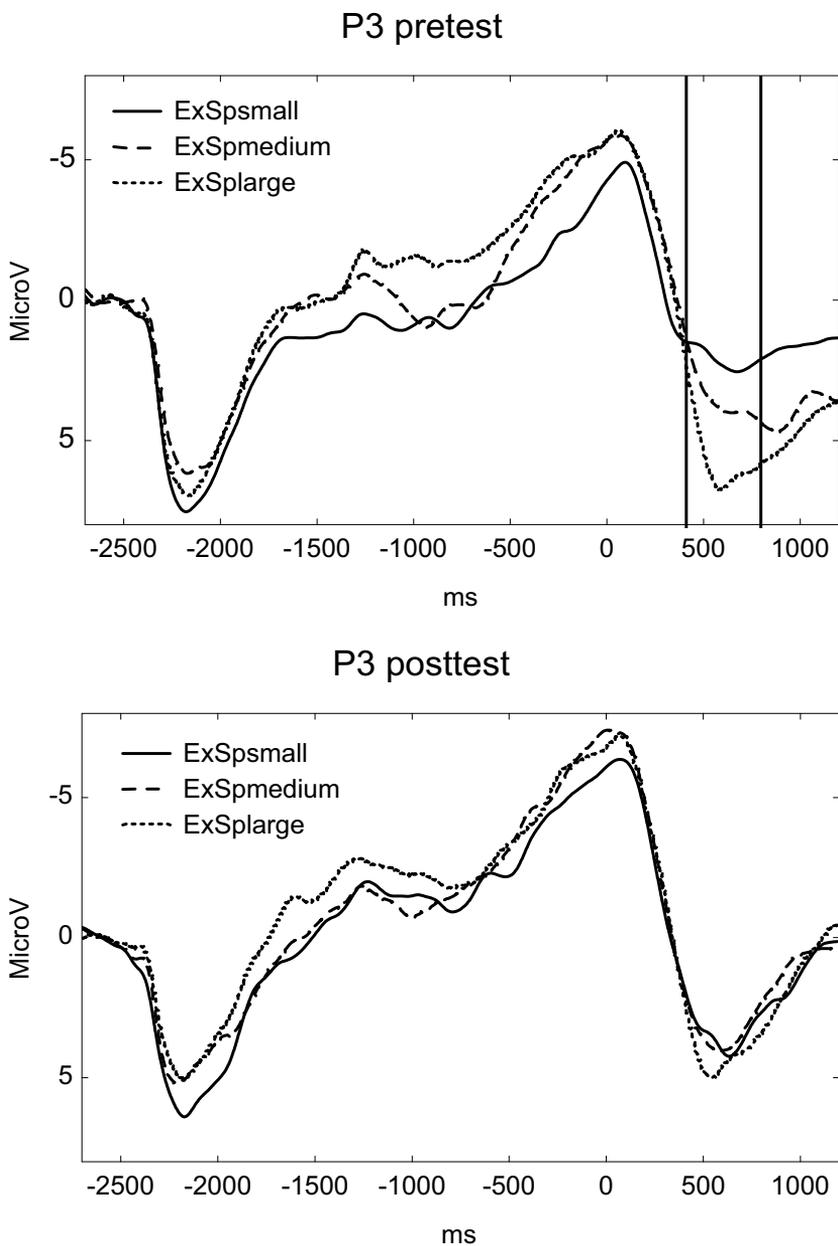


Figure 11. Pre- and posttest grand averages for the P3 electrode, with trials sorted on exit speed ratio. Marked area denote significant difference in amplitude between ExSpsmall and ExSplarge ($p < .05$, $n = 9$).

Response times

As expected, mean response time (RspT) was shorter for SAW trials than INFERRED trials. In pretest, RspT was 1630 ms ($SD = 259$) for SAW trials and 2976 ms ($SD = 1034$) for INFERRED trials, $t(7) = 3.96$, $p = .005$. (Participant S9 was excluded because she had no INFERRED responses in pretest.) In posttest, RspT was 1823 ms ($SD = 397$) for SAW trials and 3508 ms ($SD = 613$) for INF trials, $t(8) = 9.67$, $p < .001$.

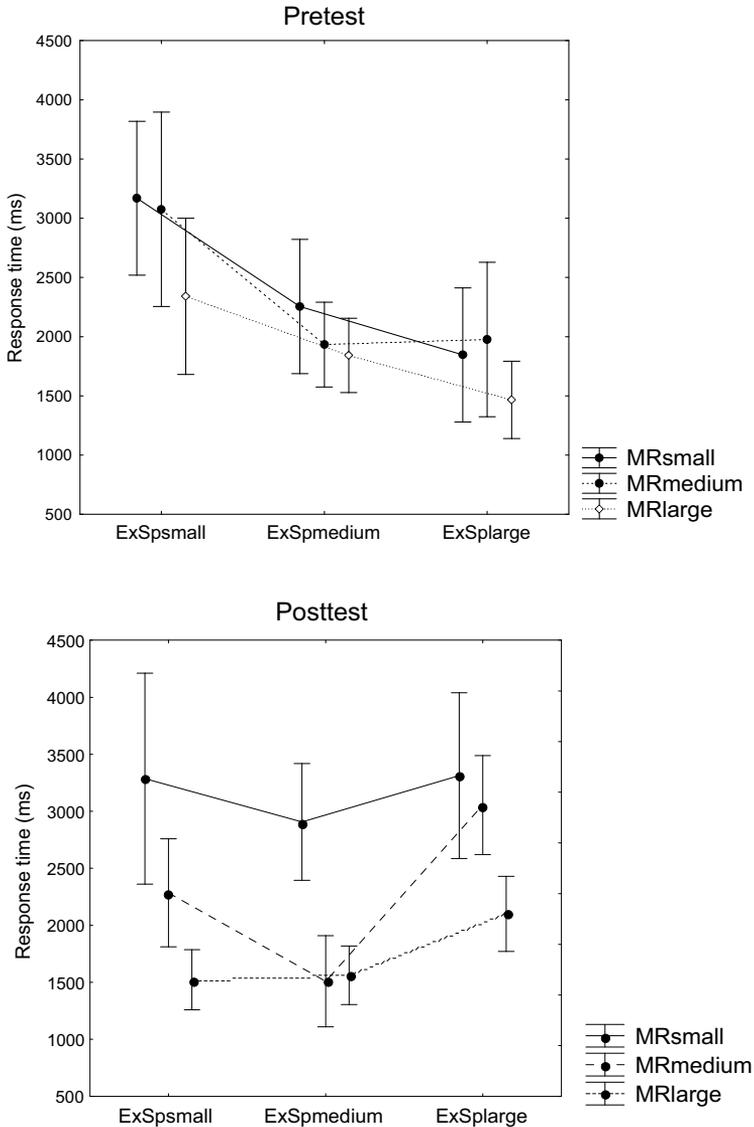


Figure 12. Mean response times in pre- and posttests for different magnitudes of mass ratio and exit speed ratio. Errorbars indicate 95 % confidence intervals ($n = 9$).

Similar to the effects on the ERPs, the magnitudes of both mass ratio (MR) and exit speed ratio (ExSp) influenced response times. For pretest, a factorial repeated-measures ANOVA with MR (3) and ExSp (3) as factors revealed significant main effects both of MR, $F(2, 16) = 13.91$, $p < .001$, and ExSp, $F(2, 16) = 11.44$, $p < .001$, and a significant interaction effect, $F(4, 32) = 3.19$, $p = .026$. In posttest, a factorial repeated-measures ANOVA with MR (3) and ExSp (3) as factors revealed significant main effects both of MR, $F(2, 16) = 34.43$, $p < .001$, and of ExSp, $F(2, 16) = 12.64$, $p < .001$, and a significant interaction effect, $F(4, 32) = 13.60$, $p < .001$. Figure 12 shows that in pretest, response times were prolonged for collisions with small exit speed ratios, whereas in posttest, they were prolonged for collisions with large mass ratios.

In sum, although participants changed from predominantly relying on the Exit-Speed variable to the mass ratio invariant, proportion SAW responses remained about the same in pre- and posttests. Both P3b amplitudes and response times differed significantly between SAW and INFERRED trials. However, all basic dependent variables (proportion SAW, P3b amplitude, and response times), tended to be related to the magnitude of the predominantly used variable, that is, to Exit-Speed in pretest and to the mass ratio invariant in posttest. Thus, the effects of reported mode on P3b amplitude and on response times are confounded with an effect of discriminability of used variables.

Study IV: Experiment 1

The usefulness of neither over/underconfidence scores nor phenomenological mode reports as mode indicators is well clarified. The mode-calibration hypothesis may be unwarranted (see findings of overconfidence for sensory tasks: Baranski & Petrusic, 1994; Kvidera & Koutstaal, 2008) and mode reports may only reflect the discriminability of the used informational variables (see Study III). The purpose of Study IV:1 was to examine whether over/underconfidence scores and mode reports are congruent mode indicators, which, if positive, would possibly strengthen both indicators. Mode reports and confidence ratings were collected in each trial. It was expected that SAW trials would yield lower over/underconfidence scores than INFERRED trials.

Participants

Twenty-eight Uppsala University undergraduate students, 20 women and 8 men, participated.

Design and procedure

Sixty-four different collisions were shown (same as in test blocks in Study I and II), with no feedback. In each trial, participants were first asked to indicate which object was the heavier, then to indicate their mode, and thereafter to indicate their confidence in the choice of object.

The definition of SAW was changed as compared to Study III. It included only the phrase "If you *had an impression, directly saw, or felt* that one of the objects was heavier".

Results

Variable usage

Mean proportion correct was 64.5 % (SD = 8.1). On group level, the Exit-Speed variable reached the best fit to data, with the highest mean R^2_{MF} correlation, .33 (SD = .22). The Mass-Ratio variable had the next highest, .11 (SD = .10), and the Scatter-Angle variable the lowest, .03 (SD = .04).

Mode reports and response times

For mode reports, trials that yielded confidence ratings of 50 % were excluded because this would denote 'a pure guess', thus reporting mode would be meaningless. Among the 28 participants, 22 rated 50 % confidence in at least one trial (up to twelve trials), and 4 % of all trials yielded confidence ratings of 50 %.

Mean proportion SAW was .46 (SD = .27). Among the 28 participants, 7 participants had 0 - 13 % SAW trials, whereas the remaining 21 had 31 - 85 % SAW trials. For the 21 participants that had 31 - 85 % SAW trials, repeated measures ANOVAs revealed no significant effect of exit speed ratio (4 categories), $F(3, 60) = 1.70$, $p = .18$, nor of mass ratio (4 categories), $F(3, 60) = .35$, $p = .79$.

Congruent with Study III, response times were significantly longer for INFERRED trials, 4609 ms (SD = 1487), than for SAW trials, 3470 ms (SD = 1649), $t(20) = 2.85$, $p < .01$, for the 21 participants that had 31 - 85 % SAW trials.

Over/underconfidence for SAW and INFERRED trials

For the 21 participants that had 31 - 85 % SAW trials, SAW trials yielded 12.4 % overconfidence (SD = 11.3) with 67.6 % correct (SD = 10.7), whereas the INFERRED yielded 17.7 % overconfidence (SD = 16.0) with 59.0 % correct (SD = 13.9). (Trials with 50 %-confidence ratings were excluded.) Since the proportion correct for SAW trials was larger than for INFERRED trials, the lower over/underconfidence scores for SAW trials could be due to the hard-easy effect. In Figure 13, over/underconfidence scores are

plotted against proportion correct for SAW and INFERRED trials for eight groups of collisions with different mass ratios. Although there was lower overconfidence scores for SAW trials than in the INFERRED trials as seen over the whole set of collisions, the graph reveals that SAW trials did not yield lower over/underconfidence scores than INFERRED trials for groups of collisions with similar proportion correct.

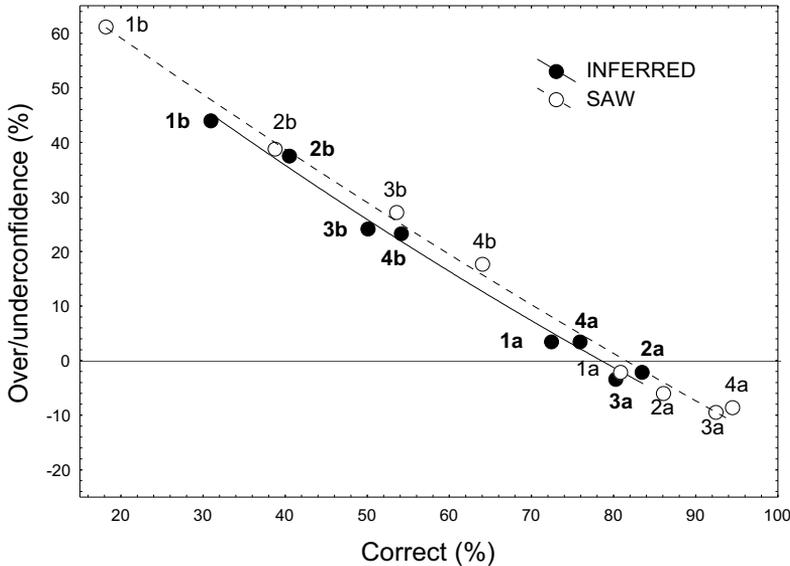


Figure 13. Over/underconfidence plotted against correctness for SAW and INFERRED trials. Dots represent results from eight categories of mass ratio. In each point, there are 56 - 107 observations. Curves are second-order polynomial functions.

From Andersson, Isabell E. K. (2009) 'Realism of Confidence and Phenomenological Reports Are Not Congruent Indicators of Modes of Apprehension in Visual Discrimination of Relative Mass', *Ecological Psychology*, 21:3, 218 — 244. Reprinted by permission of the publisher (Taylor & Francis Ltd, <http://www.tandf.co.uk/journals>).

Study IV: Experiment 2

Experiment 2 replicated Experiment 1 but with a pretest-practice-posttest design. Experiment 1 failed to confirm that SAW trials would be judged with less over/underconfidence than INFERRED trials by novices in the task. That result might be due to either that the mode-confidence hypothesis is unwarranted, or that the mode reports were not valid, or both. However, novices, who predominantly rely on the Exit-Speed variable, may have had difficulties to assign SAW and INFERRED as intended. As a possible coun-

termeasure, before the pretest in Experiment 2, an instruction block of collisions with very large mass ratios was run. Thereby novices had the opportunity to experience immediate impressions of distinct differences in mass (i.e., typical SAW cases) before the pretest, which possibly enhanced their understanding of the modes and corresponding mode reports in the pretest.

Participants

Nineteen undergraduate students, 18 women and 1 man, participated. Thirteen were recruited from a course in social care psychology as a part of a course requirement, and 6 from general courses in psychology.

Design and procedure

Sixty-four different collisions were shown (same as in Study I, II, and IV: Experiment 1). There were a pretest block (64 trials), four blocks with feedback (256 trials in total), and a posttest block (64 trials). Before the pretest, an instruction block of 24 collisions was shown, with mass ratios that ranged up to 1:8 (in previous experiments it was only 1:3 in instruction blocks).

Similar to Experiment 1, in each trial participants indicated which object was the heavier, their mode, and their confidence in the choice of object. In practice blocks, mode was not indicated. The instructions for the mode reports were identical to those in Experiment 1.

Results

Performance and variable usage

Mean proportion correct increased from 63.9 % (SD = 6.0) in pretest, to 71.3 % (SD = 9.0) in posttest. In both tests, the Exit-Speed variable reached the highest mean R^2_{MF} correlation, .40 (SD = .18) and .21 (SD = .18), respectively. The Mass-Ratio variable reached the next highest, .09 (SD = .06) and .19 (SD = .15), and the Scatter-Angle variable the lowest, .01 (SD = .01) and .06 (SD = .06). Hence, participants seem to have relied on Exit-Speed not only as novices, but to a large extent also after practice.

Mode reports

For the mode reports, trials that yielded confidence ratings of 50 % were excluded. In pretest, among the 19 participants, 13 indicated 50 % confidence in at least one trial (up to 14 trials), and 5 % of all trials yielded confidence ratings of 50 %. In posttest, 11 indicated 50 % confidence in at least one trial (up to 10 trials), and 4 % of all trials yielded confidence ratings of 50 %.

There was no significant increase in proportion SAW trials from pretest, .36 (SD = .31), to posttest, .40 (SD = .31), $t(18) = .82$, $p = .43$. In both tests, proportion SAW trials varied considerably. In pretest, 8 participants had <

15 %, 10 had 15 - 85 %, and 1 had 100 % SAW trials. In posttest, 5 had < 15 %, 12 had 15 - 85 %, and 2 had 91 - 98 % SAW trials.

Similar to Experiment 1, in pretest, repeated measures ANOVAs revealed no significant effect of exit speed ratio (4 categories), $F(3, 27) = .87, p = .47$, nor of mass ratio (4 categories), $F(3, 27) = 1.20, p = .33$, for 10 participants that had 15 - 85 % SAW trials. Also in posttest, there was no significant effect of exit speed ratio, $F(3, 33) = .08, p = .97$, nor of mass ratio, $F(3, 33) = .62, p = .61$, for 12 participants that had 15 - 85 % SAW trials.

Response times

Similar to Study III and Experiment 1, response times tended to be longer for INFERRED trials, but effects were not significant. For the 10 participants in pretest who had 15 - 85 % SAW trials, response times for INFERRED trials was 5215 ms (SD = 2532), and for SAW trials 3929 ms (SD = 1165), $t(9) = 1.81, p = .10$. For the 12 participants in posttest who had 15 - 85 % SAW trials, response times for INFERRED trials was 4492 ms (SD = 2583), and for SAW trials 3238 ms (SD = 648), $t(11) = 1.75, p = .11$. (Trials with 50 % confidence ratings were excluded.)

Over/underconfidence for SAW and INFERRED trials

In pretest, for the 10 participants that had 15 - 85 % SAW trials, SAW trials yielded 9.1 % overconfidence (SD = 7.3) with 65.0 % correct (SD = 9.5). INFERRED trials yielded 7.6 % overconfidence (SD = 17.0), also with 65.0 % correct (SD = 14.3). (Trials with 50 %-confidence ratings were excluded.) Thus, congruent with Experiment 1, SAW trials did not yield lower over/underconfidence than INFERRED trials in pretest (see also Figure 14).

In posttest, for the 12 participants that had 15 - 85 % SAW trials, SAW trials yielded -1.1 % underconfidence (SD = 13.2) with 70.3 % correct (SD = 10.8). The INFERRED trials yielded 0.3 % overconfidence (SD = 12.0) with 67.9 % correct (SD = 13.9). (Trials with 50 %-confidence ratings were excluded.) As shown in Figure 14, SAW trials did not yield lower over/underconfidence than INFERRED trials for subsets of collisions with similar proportion correct, which is similar to pretest results and results of Experiment 1

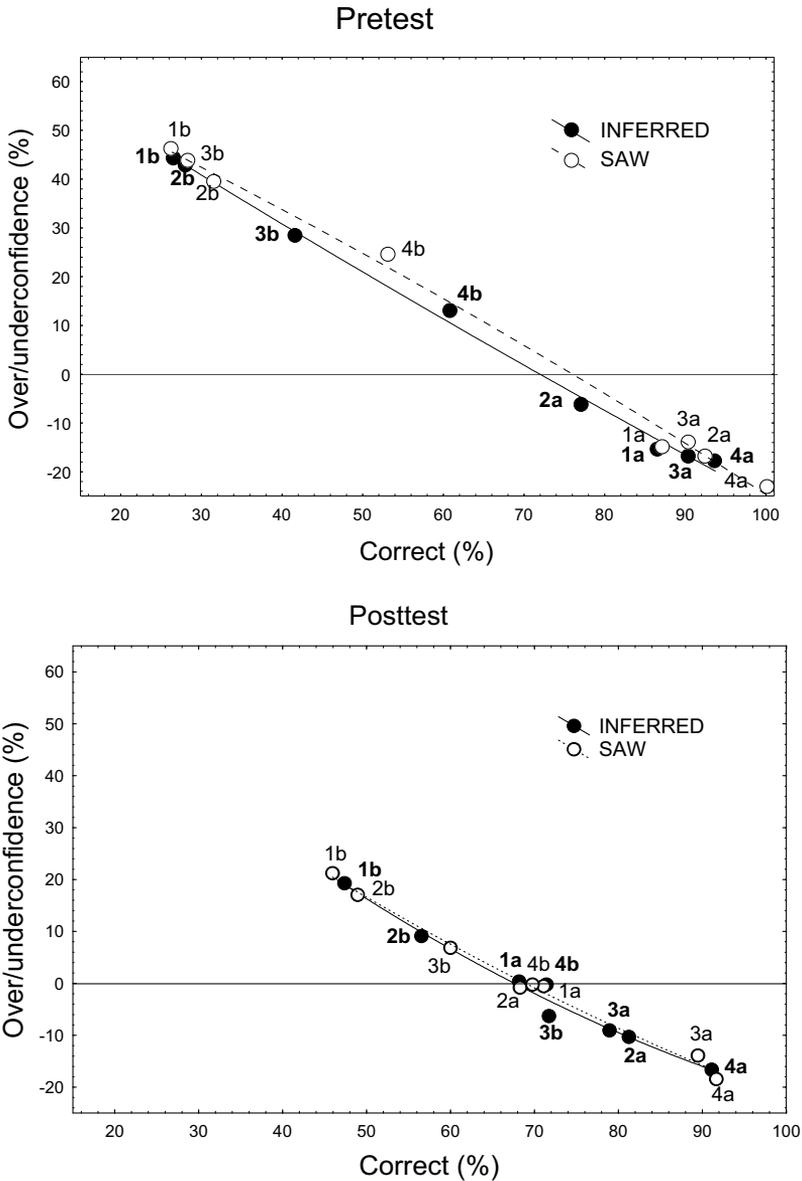


Figure 14. Over/underconfidence plotted against proportion correct for SAW and INFERRED trials in pre- and posttests. Dots represent results from eight categories of mass ratio. In each point, there are 31-47 observations in pretest, and 38-57 in posttest. Curves are second-order polynomial functions.

From Andersson, Isabell E. K. (2009) 'Realism of Confidence and Phenomenological Reports Are Not Congruent Indicators of Modes of Apprehension in Visual Discrimination of Relative Mass', *Ecological Psychology*, 21:3, 218 — 244. Reprinted by permission of the publisher (Taylor & Francis Ltd, <http://www.tandf.co.uk/journals>).

Study IV: Experiment 3

Study II found that participants who predominantly rely on the Exit-Speed variable in the mass discrimination task were quite well calibrated, both in a pretest without feedback, after normal feedback, and after feedback that encouraged usage of Exit-Speed. It was argued that the lack of underconfidence indicated that Exit-Speed was used inferentially, as a cue to the relative mass. The conclusion was based on two assumptions: that the exit speed ratio would be available for perceptual pick up, and, in line with the mode-calibration hypothesis, that if Exit-Speed had been used in the perceptual mode it would have led to underconfidence. However, it has not been tested whether discrimination of exit speed ratio as such lead to underconfidence.

In Experiment 3, participants' task was to indicate which of the objects that moved the fastest after the collision moment, and indicate their confidence in their judgments. That is, the participants were to base their choices on the Exit-Speed variable, and the information used would thus be identical with the exit speed cue in the mass discrimination task. It was assumed that discrimination of exit speed ratio is a perceptual task, and in line with the mode-calibration hypothesis, thus participants were expected to be underconfident.

Participants

Eleven undergraduate students, three women and eight men, participated. They were recruited both from the Department of Psychology and from other departments at the University (Economy, Law, etc.).

Design and procedure

Thirty-two different collisions were shown, presented twice in two randomly permuted blocks, totally comprising 64 trials. To prevent the task from being too easy, the collisions had somewhat smaller exit speed ratios than in previous experiments.

The participants' task was to indicate which of the objects that moved the fastest after each collision. After each choice, they indicated their confidence in their judgment. No feedback was given.

Results

Participants were quite well calibrated, with -0.5 % underconfidence with 89.0 % correct. To obtain a midrange set of collisions that would center around 75 % correct (where the hard-easy effect is considered neutral), a subset of collisions was created containing collisions with 68 - 82 % correct ($n = 8$). For the subset, there was 1.2 % ($SD = 13.5$) overconfidence with

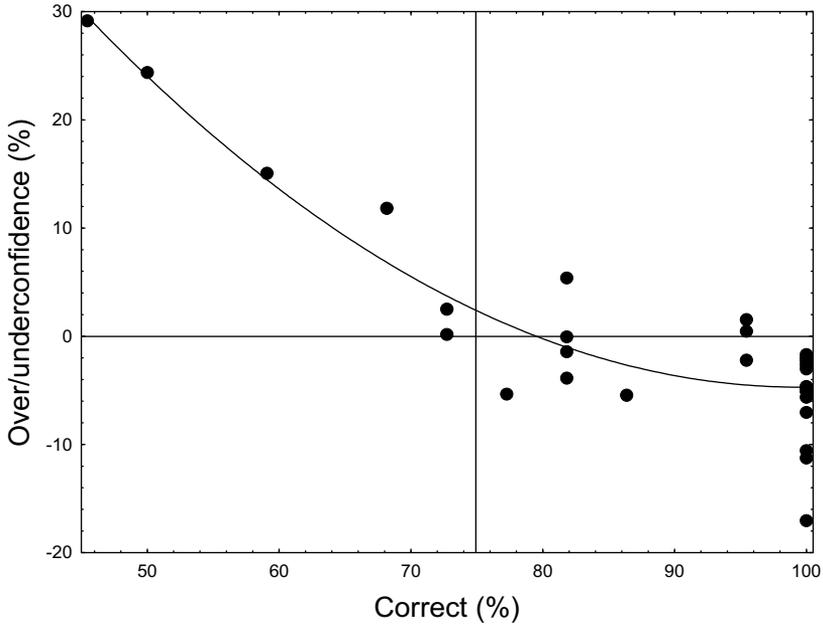


Figure 15. Over/underconfidence plotted against proportion correct for judgments of relative exit speed. Dots represent results from each of the 32 collisions. Each collision was judged twice by each participant, so there were 22 responses for each collision. Curve is a second-order polynomial function.

From Andersson, Isabell E. K. (2009) 'Realism of Confidence and Phenomenological Reports Are Not Congruent Indicators of Modes of Apprehension in Visual Discrimination of Relative Mass', *Ecological Psychology*, 21:3, 218 — 244. Reprinted by permission of the publisher (Taylor & Francis Ltd, <http://www.tandf.co.uk/journals>).

77.3 % (SD = 9.8) correct. In Figure 15, over/underconfidence scores are shown for each collision. Interpolation at 75 % correct gives a few percent overconfidence, which agrees with the subset calculation. Thus, there was no general underconfidence bias in this task.

Discussion

The main aim of the thesis was twofold: to investigate the mode-transition model of skill acquisition in the relative mass discrimination task, and to explore methods to empirically distinguish the modes of apprehension. In the following sections, results for each mode indicator are discussed. The results of each study will thus be treated under several headings.

Main findings and their limitations

Variable usage and learning

For novices, on group level, in all studies the Exit-Speed variable reached the best fit to performance data, among the candidate variables tested. This is congruent with previous results in the relative mass task (Jacobs et al., 2000; Jacobs, Runeson, & Michaels, 2001; Runeson et al., 2000; Runeson & Vedeler, 1993; see also Gilden & Proffitt, 1989). However, individual level analyses in Study I show that a minority of novices relied on the mass ratio invariant (see also Study III, Figure 7, according to which some novices reached higher correlation with the invariant than to Exit-Speed). This indicates that novices differ in the kinematic variable they rely upon in this task (cf. Jacobs et al., 2000; Jacobs, Runeson, & Michaels, 2001; see also Michaels & de Vries, 1998; Withagen & Michaels, 2005, for similar findings in other paradigms). Moreover, it indicates that the ability to judge relative mass based on an analytically complex informational variable is not necessarily feedback dependent.

In Study I, after practice with normal feedback, on group level the mass ratio invariant reached the best fit (on individual level 7 of 10 participants learned to use the mass ratio invariant). Also in Study III, the invariant reached better fit than Exit-Speed after practice (cf. Figure 7). This is congruent with Runeson et al.'s (2000) finding of a change from reliance of nonspecifying variables to reliance on the mass ratio invariant after practice. In Study IV:2, however, in which the practice conditions and test blocks

were identical to those in Study I, participants as a group continued to use Exit-Speed after practice.⁹

In Study I, a further three groups received feedback based on nonspecifying variables. In the Exit-Speed feedback group, all participants continued to rely on Exit-Speed after practice. In the Scatter-Angle and Sweep-Speed groups only about half of the participants came to rely on the feedback variables, and two participants in each group came to rely on the mass ratio invariant. This shows that performance in this task is not necessarily feedback dependent. If participants thus had some notion about how to judge the relative mass based on the invariant, they may have faced a conflicting task in these conditions. Indeed, some participants in the Sweep-Speed and Scatter-Angle groups spontaneously questioned the feedback given. Thus, the cases of feedback dependence found in those "false" feedback groups may be irrelevant for normal learning paths.

However, as a general caveat, it should be noted that classification of variable usage, both on individual and on group level, only suggests which variables were *predominantly* used in the analyzed blocks of trials. As pointed out in Study II, it is likely that variable shifts occurred within the blocks. For example, in Study II (and I) for participants classified as invariant users, proportions correct for groups of collisions with the same mass ratio differed depending on the supportiveness of the exit speed cue. As can be seen in Figure 5, groups of collisions with mostly supporting exit speed cue (# -4 to # -1) generally yielded larger proportions correct compared to the corresponding reversed mass ratios, with mostly contradicting exit-speed cue (# 1 to # 4), both for novice and after-practice invariant users. This asymmetry in the distribution of errors suggests that Exit-Speed was used to some extent, even though the mass ratio invariant reached the best fit for these participants and they thus were classified as invariant users. Not only is it likely that participants changed what variables they used within the blocks, but it is also quite possible that other untested variables, or combinations of variables, may have been used. However, Study I showed that post hoc weighted linear combinations of Scatter-Angle and Exit-Speed rarely reached a better fit than the mass ratio invariant. Generally, the classification of variable usage should be taken with caution. This is particularly critical for Study II, in which the effects of variable usage on over/underconfidence level were tested.

⁹ In Study IV it was speculated whether the quite limited learning effect could be explained by participants' lack of motivation or interest. Participants in Experiment 2 were more or less required to participate in order to receive course points and their main field of study was not psychology. Motivation might be formulated in terms of intention, and different intentions are presumed to organize perceptual systems in different ways (e.g., Jacobs & Michaels, 2002). Unlike participant groups in earlier studies, in Experiment 2 the participants nearly all were females. However, earlier informal observations have not indicated a gender difference in performance in this task.

Realism of confidence

The mode-calibration hypothesis refers to the idea that the mode of apprehension would be reflected in participants' realism of confidence. (Rune-son et al. 2000, cf. Juslin & Olsson, 1997; Juslin et al., 1998). Specifically, perceptual-mode functioning would lead to underconfidence, whereas inferential mode functioning would lead to overconfidence or good calibration. Note that there is an asymmetry in that perceptual-mode over/underconfidence would be below zero, whereas inferential-mode over/underconfidence would be above, or include, zero. In Study II and IV:3, participants' over/underconfidence levels were assessed and related to variable usage and learning, which is discussed below. In Study IV:1 and 2 over/underconfidence levels were related to reported mode. This is discussed in Discussion: Mode reports and over/underconfidence scores combined.

Over/underconfidence for Exit-Speed users

One purpose of Study II was to test whether nonspecifying variables were used in the inferential or the perceptual mode, as indicated by over/underconfidence levels. Among the candidate nonspecifying variables, Exit-speed was by far the most used (see above), so analyses were limited to this variable.

Both novice Exit-Speed users and Exit-Speed users after normal practice, were well calibrated or slightly overconfident, when over/underconfidence was scored against Exit-Speed. The lack of underconfidence suggests that Exit-Speed users were functioning inferentially both before and after practice. Thus, the exit speed relation seems to have been used as a cue to the relative mass. Also Exit-Speed users that had received feedback based on Exit-Speed were quite well calibrated after practice. This suggests that participants continued to use the variable inferentially, as a cue, despite that feedback suggested that Exit-Speed was a variable specifying relative mass.

These interpretations are not unproblematic however. First, one could question whether scoring over/underconfidence against individuals' most fitting variable, in this case Exit-Speed, was a useful method. The purpose was to remove over/underconfidence that was elevated by a mismatch between the experimenters' criterion of performance, and the variable actually used (Hajnal et al., 2006). That is, overconfidence due to Brunswikian errors (errors due to usage of cues, or informational variables, with low validity) was to be removed. Presumably, possible underconfidence would then be revealed. If underconfidence thus had emerged, it would have indicated that participants had used the nonspecifying variable in the perceptual mode. (That is, they would have based their confidence on variability of sensory impressions and not on the apparent cue validity, see Juslin & Olsson, 1997). Variable usage was assessed block-wise, using the highest R^2_{MF} correlation as the criterion for individuals' categorization of variable usage. However, as

noted above, it is not unlikely that judgments were based on other variables in some trials, despite that Exit-Speed was the most fitting variable over blocks. In particular when comparisons were restricted to subsets of collisions that centered around 75 % correct, it is very likely that those subsets contained a substantial part of trials that was judged based on other variables than the variable scored against. If so, the over/underconfidence scores for the subsets could still be elevated due to mismatch between the best fitting variable and the variables actually used. This problem was discussed in Study II, and it was concluded that, ideally, one should track variable usage trial by trial.

Furthermore, in the light of the results of Study IV:3, one could question whether the lack of underconfidence for Exit-Speed users in the relative mass task in Study II indeed indicates that Exit-Speed was used as a cue to relative mass. Instead, the good calibration for Exit-Speed users in Study II could have been due to inferential processes when judging the relative exit speed as such. In study IV:3, the task was to indicate which object moved the fastest after collision. The information then used would likely be identical with the information that Exit-Speed users use when judging the relative mass. In Study IV:3, there was no general underconfidence for judgments of the exit speed relation. This suggests that the exit speed relation as such is obtained inferentially using cues.¹⁰

In Study IV, it was discussed whether judgments of relative exit speed required, or encouraged, inferential functioning. In Study I it was shown that the exit speed relation is specified by, for example, the orientation of an (imaginary) rod connecting the objects when they move out of the collision. When the objects move with different speeds, the rod is tilted towards the slower object relative to the origin of the movements (i. e., the collision point), or, to the common motion direction. Picking up the direction of the tilt would give an impression of the relative exit speed and thus be sufficient for discriminating the speed relation. However, possible inferential ways to judge the exit speed relation was also discussed. For example, the task could be transformed to a temporal matter in that the object that reaches the edge of circular display field first could be judged to be the fastest. This was not always correct however, because the position of the collision point was not centered, and it varied randomly from trial to trial. Unfortunately, the experimental setup in Study IV did not allow for these alternatives to be tested because position of the collision point was not registered.

¹⁰ The basis for the judgments of the exit speed relation, and thus the basis for the confidence ratings (cf., Juslin & Olsson, 1997; Juslin et al., 1998), could be different in the two tasks however. There is the possibility that when the task was to judge relative exit speed, observers buttressed the judgments by cues such as timing of the objects reaching the border of the screen. In the relative mass task, on the other hand, it is possible that the exit speed relation was perceptually picked up, for subsequent use as a cue to the relative mass. Since the tasks differed, the means of judging the same relation may also have differed.

In sum, the lack of underconfidence for Exit-Speed users in the relative mass discrimination task seems to indicate that they functioned in the inferential mode and that relative exit speed was used as a cue to relative mass. However, the method used for assessing over/underconfidence for Exit-Speed users may not have been sufficient. Moreover, the lack of underconfidence for judgments of the exit speed relation as such suggests that the relation was obtained inferentially. The lack of underconfidence for Exit-Speed usage in the relative mass task may thus be reflecting inferential functioning when the relative exit speed itself was judged, and not necessarily that the relative speed relation was used as a cue to relative mass.

Over/underconfidence for invariant users

In Study II, novice invariant users were overconfident, whereas after-practice invariant users were slightly underconfident. The difference between the pre- and posttest invariant users was only approaching statistical significance (over all collisions). Nevertheless, for groups of collisions that had similar proportions correct, over/underconfidence scores were always lower for the after-practice invariant users than for the novice invariant users (see Figure 5). This suggests that there was a true difference between the groups. It can also be noted that the single participant who was categorized as invariant user in both pre- and posttests changed from clear overconfidence to slight underconfidence. According to the mode-calibration hypothesis, the overconfidence for novice invariant usage indicate inferential functioning, whereas the slight underconfidence in posttest provides at least a hint that they functioned more in the perceptual mode after practice.

The finding of overconfidence for novice invariant users suggests that they judged the mass ratio inferentially, based on cues. However, Runeson et al. (2000) argued that performance characterized by usage of the mass ratio invariant could not be a result of inferential functioning because it would require pick up of several motion components and advanced inferential reasoning to combine those components. According to Runeson et al., such an explanation would be unparsimonious, as compared to a single-step pick up of the invariant. This argument is weakened, however, if one considers that inferences may be based not only on analytically simple variables, such as speeds and directions. If instead complex variables were picked up, then inferences would not need to be advanced. In Study I, the so-called common motion deflection was suggested to be a possible basis for perception of the relative mass. That is, by pick up of the common motion deflection, observers would get an impression of the relative mass. However, the common motion deflection may as well serve as input for an inference based on a rule saying "the common motion deflects away from the heavier object". That is, observers may pick up the deflection, and according to this simple rule infer which object is heavier. If they then base their confidence ratings on this cue,

such a scenario might explain the overconfidence for novice invariant users in Study II.

However, novice invariant users' overconfidence may be an artifact, similar to that regarding Exit-Speed users considered above. Although the mass ratio invariant was the best fitting candidate variable for these participants, it is highly likely that they shifted in variable usage within the block. If some of the collisions were judged based on other variables, it is possible that those variables were used inferentially, which would elevate the over/underconfidence scores. In addition, if other variables were sometimes used, the over/underconfidence scores would be elevated due to a mis-match between the variables used and the scoring of correctness (cf. Hajnal et al., 2006). Although such an explanation might generally be considered, shifts in variable-usage were not likely to explain why novice invariant users tended to be more overconfident than after-practice invariant users. Performance both in terms of overall proportions correct and of R^2_{MF} was similar before and after practice. In addition, when comparing proportions correct for corresponding mass ratios (see Figure 5), it seems that performance in pre- and posttest was most often similar also for subsets of collisions. This indicates that possible within block shifts in variable-usage occurred to the same extent before and after practice. Hence, the higher over/underconfidence for novices, as compared to the posttest invariant users, is not likely explained by more use of nonspecifying variables for the novices.

Another possible explanation for the lower over/underconfidence scores after practice is that practice, or feedback, would generally reduce the confidence levels. Research does not support this idea however, neither for perceptual tasks (e.g., Petrusic & Baranski, 1997; Björkman et al., 1993; Stankov & Crawford, 1997; Winman & Juslin, 1993), nor for cognitive tasks (e.g., Stankov & Crawford, 1997; Subbotin, 1996; but see also Winman & Juslin, 1993).

A more likely explanation for the lower over/underconfidence scores after practice would be in terms of individual differences, since the pre- and posttest invariant users were different individuals (except one). Research has shown that there are individual differences in the level of over/underconfidence (Blais, Thompson, & Baranski, 2005; Klayman, Soll, Gonzales, & Barlas, 1999; Kleitman & Stankov, 2001; Stankov & Crawford, 1996). Unfortunately, such individual differences in over/underconfidence would render over/underconfidence levels unreliable as mode indicator for small samples, as well as on the individual level, and make it necessary to employ within-subjects designs, which was not the case in Study II.

Arguments against realism of confidence as mode indicator

A general objection against using over/underconfidence level as indicator of mode is that the mode-calibration hypothesis may be unwarranted. Perhaps over/underconfidence scores do not well enough reflect, or are unre-

lated to, mode. The mode-calibration hypothesis is based on the idea that over/underconfidence levels differ between perceptual and cognitive tasks (e.g., Juslin & Olsson, 1997; see also Björkman et al., 1993; Juslin, Olsson, & Winman, 1998; Olsson & Winman, 1996). This idea is not uncontroversial however. Some argue that confidence in sensory and cognitive tasks originates in the same types of process, that and that there is no principled difference in over/underconfidence between those tasks (Baranski & Petrusic, 1994, 1999; Ferrell, 1995; Suantak et al., 1996).

Further supporting the latter position, a recent study that compared perceptual with conceptual judgments for the same stimuli (pairs of words) found more overconfidence for perceptual than conceptual judgments (Kvidera & Koutstaal, 2008; see also Baranski & Petrusic, 1995, for overconfidence in sensory tasks). Kvidera and Koutstaal (2008) concluded that "while underconfidence may be a common finding for the typical decision tasks used [e.g., line or weight discrimination, Juslin et al., 1998] underconfidence is not the inevitable outcome for all perceptual decisions" (p. 274). Furthermore, Kvidera and Koutstaal (2008) found substantial within-person but across-task correlations of over/underconfidence levels. Together with findings of individual differences in over/underconfidence (Blais et al., 2005; Klayman et al., 1999; Kleitman & Stankov, 2001; Stankov & Crawford, 1996), this shows that not only task characteristics influence the level of over/underconfidence.

The findings discussed above concerned tasks that a priori were categorized as perceptual/sensory or cognitive/conceptual. However, it is not unlikely that at least some tasks required both sensory and cognitive components, in various proportions (cf. Juslin & Olsson, 1997). Kvidera and Koutstaal also noted that "our perceptual decisions were themselves somewhat 'higher level' (i.e., perceptual judgments rather than purely sensory judgments)" (p. 275). Thus, their perceptual task might have required not only sensory discriminations but also cognitive or inferential components.

Even though tasks characteristics, and mode, indeed would be reflected in over/underconfidence level, it is questionable whether inferential functioning necessarily would lead to overconfidence or good calibration in tasks that require perceptual discrimination of cues, such as in the mass discrimination task. As noted above, for inferential functioning it is assumed that the confidence ratings reflect participants' notions of the validity of cues (e.g., Gigerenzer et al., 1991). However, when cues are to be perceptually discriminated, there is the possibility that observers base their confidence ratings not only on the apparent cue validity, but also on how well the cue was discriminated. If confidence ratings were based only on the discriminability of cues, it might lead to lowered over/underconfidence scores or even underconfidence. Although Exit-Speed usage was not connected to underconfidence in the studies, this argument points to a further general problem with using

over/underconfidence level as a mode indicator in tasks that require perceptual discrimination of cues.

Summary

Invariant users in the mass discrimination task changed from overconfidence to slight underconfidence, which suggests that they functioned inferentially as novices but changed towards perceptual functioning during practice. This is congruent with the mode transition model of skill acquisition (Runeson et al., 2000). Participants who used the Exit-Speed variable in the mass discrimination task were well calibrated both before and after practice, which suggests that the nonspecifying variable was used inferentially, as a cue to the relative mass. Participants who judged the relative exit speed as such were well calibrated, which suggests inferential functioning also in this task. The main limitations of these interpretations are: a) participants may have used different variables within the blocks, b) the re-scoring of Exit-Speed users' over/underconfidence did not help to remove scores elevated by Brunswikian errors, c) the mode-calibration hypothesis may be unwarranted.

Mode reports

In Study III and IV:1 and 2, phenomenological mode reports were collected. In the two that were learning studies (III and IV:2), proportion SAW responses remained about the same before and after practice. Thus, on group level, in neither of the studies did mode reports indicate that mode transitions had occurred.

Proportion SAW responses varied considerably among participants. In Study III, novice participants had 30 - 100 %, whereas after practice they had 34 - 90 % SAW responses. In Study IV:1 and 2, novices had 0 - 100 % SAW responses, whereas after practice in Study IV:2 they had 0 - 98 % SAW. If individuals differ to such a large extent in their mode, irrespectively of the phase in learning, mode functioning may perhaps more be a matter of individuals' approaches to the task, perhaps analogous to individuals' "cognitive styles" (e.g., Rayner & Riding, 1997; Witkin, Moore, Goodenough, & Cox, 1977), or perhaps individuals' "attitude" to the task (cf. Heft, 1993). However, the large individual differences in proportion SAW might instead be due to differences in individuals' mode criteria, or understanding of instructions, which severely casts doubt on the validity of the mode reports in the present experiments.

The mode reports were not unsystematically assigned however. In Study III, on group level, the proportion SAW increased with magnitude of the mass ratio, in particular in posttest. That large mass ratios would yield more SAW responses was expected, because in such cases the mass ratio invariant would presumably be easier to discriminate (cf. Runeson et al., 2000); it would be easier to "see" which object was the heavier. However, in pretest,

proportion SAW increased also with magnitude of exit speed ratio. This suggests that for novices, who as a group predominantly relied on the Exit-Speed variable, perceptual-mode functioning could also have occurred in collisions with distinctive difference in exit speed. But does this indicate that they "saw" which object was the heavier when the exit speed ratios were large, that is, did they function in the perceptual mode?

Also in Study IV:1 and 2, Exit-Speed was the predominantly used variable before practice, and remained so after practice in Study IV:2. In those studies, however, proportion SAW was not related to Exit-Speed magnitude. A possible explanation for this difference between Study III and IV is that the instructions for the SAW mode differed. In Study III, but not in Study IV, the definition of SAW included phrases like "if you used a feeling or your intuition". One might speculate whether such a definition of SAW led participants in Study III to base their mode reports on the discriminability or salience of the exit speed relation, irrespectively of how the variable was then used in the mass ratio judgments. Even if they used the exit speed relation as a cue to relative mass, they might have taken "a feeling or intuition" to be an appropriate description. In cases when the exit speed relation was less salient or harder to discriminate, they might have been forced to look for other cues and less straightforward inferences, which might have evoked more INFERRED responses. In Study IV, in contrast, it was stressed that SAW should be indicated only when the chosen object "looked heavier". That the relative exit speed did not influence reported mode in Study IV could be an effect of a less ambiguous mode instruction.

Generally, it is not clear how well the instructions for the mode reports captured the phenomenological aspect of respective mode functioning. As an attempt to validate the mode reports, response times and ERPs for SAW and INFERRED trials were compared (see below).

Response times

Congruent with Kreegipuu and Runeson (2000), both in Study III and IV:1 response times were significantly longer (1 second or more) in INFERRED trials than in SAW trials. In Study IV:2, there was a similar, albeit not significant, effect. The consistent response time difference indicates that the mode reports indeed captured something of the process underlying choice of object.

However, a difference in response time does not necessarily reflect a difference in mode, and inferential mode functioning would not necessarily require longer time than perceptual-mode functioning. If an observer consistently uses a particular informational variable together with a certain rule, response times would likely not be prolonged, although this would be a case of inferential functioning. There is the possibility that choice of cue variable (as for instance the popular Exit-Speed variable) and accompanying rule was

done before the collisions unfolded. Such a choice could have been established during the first few collisions, and then maintained over a sequence of collisions. If an observer consistently uses such an established rule-variable complex, presumably no additional time would be required beyond the time it takes to detect the informational variable. In such case, the assumption that inferring would be reflected in response times would be unwarranted, and response times could not uncritically be taken to support the validity of the mode reports.

In Study III, response times decreased with magnitude of the respective predominantly used variable. Novice observers tended to be fastest when exit speed ratios were the largest, whereas after practice they tended to be fastest when mass ratios were the largest. Also mode reports were related to exit speed ratios in the pretest, and to mass ratios in the posttest. Hence, discriminability of the predominantly used variable, instead of the presence or absence of inferential processes, may explain the difference in response times between SAW and INFERRED trials. The prolonged response times for small ratios of the used variables could instead be due to prolonged inspection of the collisions, and a search for other variables perhaps in combination with *further* inferential processes. In Study IV, however, neither the response times, nor the reported mode were related to magnitude of the variables.

In sum, the consistent response time difference between SAW and INFERRED trials indicates that the mode reports indeed captured something of the process underlying the choice of object, but it is unclear whether mode was reflected or whether only discriminability, or salience, of informational variables was reflected.

Event-related potentials

In Study III, event-related potentials (ERP) elicited during the collisions exhibited a relatively large positive deflection 400 - 800 ms after the collision moment, particularly in parietal electrodes. The polarity and maximum location fits the definition of the well-studied P3b component of the ERP (e.g., Rugg & Coles, 1995). The P3b component is elicited by stimuli that require some sort of response (target stimuli) (e.g., Fabiani et al., 1987). Providing that the moment of collision qualifies as the time in which target stimuli appear, also the latency range fits the definition of P3b.

As expected, SAW trials elicited significantly larger P3b amplitude than INFERRED trials, both in pre- and posttests. This difference was also visible in a majority of individual ERPs. Adopting Kotchoubey's (2002, 2006) view that P3b would be related to extraction of target information, the large amplitudes in SAW trials suggest that in these trials observers managed to extract the *to them* relevant and target-like information to a high degree. In the INFERRED trials, in contrast, the smaller amplitudes would be due to less

target information extraction, perhaps together with an amplitude reduction due to additional cognitive processing (e.g., Verleger, 1988). Under this interpretation of P3b generation, the ERP results support the validity of the mode reports.

P3b amplitude also increased with magnitude of exit speed ratio in pretest and with mass ratio in posttest (see Figure 11). This result is important because it provides psychophysiological evidence that participants attended to different informational variables before and after practice, which independently corroborates the variable-usage analyses by means of R^2_{MF} correlations.

Note that the effects of reported mode and magnitude of the predominantly used variables on P3b amplitude are confounded. In pretest, collisions with larger exit speed ratios elicited larger amplitudes but also relatively more SAW responses than smaller exit speed ratios, whereas in posttest collisions with larger mass ratio elicited larger amplitudes and more SAW responses than smaller mass ratios. The posttest results were expected, providing that participants found the mass ratio invariant to be the target information, and that it was more easily extracted in collisions with larger mass ratio.

But why did large exit speed ratios lead to large amplitudes for novices? One interpretation is that the exit speed relation appeared to specify relative mass, and thus to be the target information. According to the mode reports, novices tended to judge collisions with large exit speed ratios in the perceptual mode. That is, for novices the slower object may *look* heavier. Thus, novices' high P3b reactivity to large exit speed ratios is congruent with the idea that nonspecifying variables at least under some conditions are used in the perceptual mode (cf. Withagen, 2004).

An alternative interpretation is that for novices the exit-speed relation was the target information, but not in the sense that it provided an impression of the relative mass. Instead, the relation could have been seen as the relevant cue that led to a mass ratio judgment via a rule. That is, novices may have attended to the exit speed relation as such, and the extracted information may have been used as cue in an inferential mode. When this re-defined target information was salient or easily discriminated, large P3b amplitudes were elicited. However, in such case, novices' mode reports would be misleading and their SAW responses for larger exit speed ratios would only indicate that they "saw" the cue. As noted above (under Mode reports), they may have considered SAW to be the appropriate response when a cue variable was salient or clearly discriminated.

Mode reports and over/underconfidence scores combined

As discussed above, over/underconfidence scores are not an unproblematic mode indicator. Also the validity of mode reports is unclear. In Study

IV:2 and 3, in each trial participants both reported their mode and rated their confidence in the mass ratio judgments. The purpose was to examine whether over/underconfidence scores and mode reports are congruent mode indicators. It was expected that participants would be more underconfident in trials in which they indicated SAW than in trials they indicated INFERRED.

In neither of the experiments did SAW trials yield more underconfidence than INFERRED trials. Although in Study IV:1 there was lower overconfidence scores for SAW trials than for INFERRED trials over the whole set of collisions, the SAW trials did not yield lower over/underconfidence scores than INFERRED trials for groups of collisions with similar proportion correct (i.e., when the hard-easy effect was considered). Also in Study IV:2, SAW trials did not yield lower over/underconfidence than INFERRED trials, neither in pre- or posttests. Although a null result could not be taken as evidence, these results suggest that either over/underconfidence scores, or mode reports, or both, do not well enough distinguish the modes of apprehension.

Conclusions

One aim of the thesis was to examine Runeson et al's (2000) mode transition model of perceptual skill acquisition by means of four possible mode indicators. Taken at face value, neither of the learning studies revealed a transition in mode during practice. In many cases, participants changed from reliance on nonspecifying variables to reliance on the mass ratio invariant, but, according to the mode indicators, this change was generally not accompanied by a change in mode. An additional conclusion suggested by the studies taken together is that usage both of the invariant and the Exit-Speed variable might occur either in the inferential or in the perceptual mode. Such a conclusion is inconsistent with the assumption that usage of the mass ratio invariant by necessity occurs in the perceptual mode (cf. Runeson et al., 2000), but is partially consistent with Withagen's (2004) notion that nonspecifying variables are used perceptually without inferences.

However, as discussed above, the mode indicators, as least as they were implemented in these studies, can be questioned both on methodological and conceptual grounds. In particular, results from Study IV suggest that either over/underconfidence levels or introspective mode reports do not indicate mode as intended. If forced to choose, in the light of the controversy regarding the basis for confidence ratings (e.g., Baranski & Petrusic, 1994, 1999) it seems that the hitherto most promising mode indicator is introspective mode reports. Both response times and the ERP amplitudes in Study III appear to support the validity of the mode reports. But, as discussed above, these effects might be due to discriminability of the used variables, instead of differences in mode of functioning. However, as pointed out by Runeson et al. (2000, p. 550), discriminability, at least of the mass ratio invariant, would

also be related to mode functioning in that difficulties of discrimination could lead to search for cues and usage of inferences. For further studies, it might be fruitful to more systematically examine effects of discriminability on reported mode.

In addition, the less than straightforward interpretations may be due to the present conceptualization of mode functioning. In the studies it was initially assumed that each trial, or even block of trials (Study II), would be performed in one and the same mode. However, in the relative mass discrimination task, which provides a dynamic and relatively "rich" task environment, there is the possibility of interplay between perceptual and inferential functioning even in single trials. The collisions are evolving events in which specificational information occurs as a momentary change, while a non-specificational variable (Exit-Speed) is available for an extended time. Even though observers may pick up the specifying variable, they may in addition try to buttress their impression with inferences based on cues that are easily discriminated and available for a longer time. It is quite likely that perceptual and inferential functioning occurs more or less in concert, at least when observers are faced with tasks other than pure sensory.

Moreover, it is not entirely clear how to delineate inferential mode functioning. The definition of the inferential mode employed in the studies was more restricted than in Runeson et al. (2000). In the present studies, it was defined as observers' conscious and deliberate usage of rules in conjunction with informational variables. The inferential mode would thus not be an instance of indirect perception, as entailed for instance in Rock's (1983) notion, nor constitute usage of "perceptual heuristics" that Hecht (2000) discussed in the context of dynamic event perception. However, a more precise description of inferential mode functioning is still lacking. For instance, consider an observer who believes, or has learned to believe, that the object moving faster after the moment of collision is the lighter, and thus consistently uses this rule-variable complex. Attention would be directed towards the relative speed of the objects, and responses would be made according to the rule. But would such a belief necessarily constitute "conscious and deliberate usage" of the rule (which is a prerequisite for introspection-based measures)? If a more specific description of inferential mode functioning is developed, perhaps better mode indicators could be found.

In sum, before studying perceptual and inferential functioning and mode transitions in natural and complex task environments, it would possibly be fruitful to look for empirical evidence for the mode distinction, and the mode-transition model of perceptual skill acquisition, in more simple experimental paradigms. Furthermore, it is necessary to develop a more precise description of the modes, a hypothesis of how the modes would be co-existing and interrelated, and also to consider how the mode distinction is related to the notion of direct perception.

Direct perception and the inferential mode

Is there a place for a distinction between two modes of apprehension within the direct-perception framework? And, what would be the function of an inferential mode?

Under the heading “Myths about direct perception” Shaw (2003) writes about ecological psychologists and inferences, “We do not and should not deny a legitimate role to inference as a cognitive process; however, we prefer to construe it as a way of linking current indirect evidence, perhaps through mediating propositions, to future or past direct experiences. To evaluate the indirect evidence one must ultimately link it up to directly specified evidence.” (p. 83). Thus, perception is the primordial function, and the way to ground knowledge, but inferences could serve to link “indirect evidence” (i.e., cues) to that which is already known through perception. In Warren's (2005, p. 344) words, “low-probability, partially diagnostic relations may be exploited by inferential cognitive processes...but our primary perceptual contact depends on high-probability, specific information — including our perceptual contact with the material clues...that provide premises for cognitive inference processes”.

Gibson (1966, p. 303-304) pointed out that when information is conflicting, masked, equivocal, cut short, reduced, or false, a search for additional information begins, “the system hunts more widely in space and longer in time. It tests for what remains invariant over time, trying out different perspectives.” If this also fails, “a whole repertory of poorly understood processes variously called assumptions, inferences, or guesses come into play. Merely probable information, clues or cues, is not as satisfying for the perceptual system as the achieving of clarity...but guessing does occur in highly complex situations”. It is all about the “*search for meaning*” [original italics]. According to Reed (1988), Gibson considered perception to be “one of many modes of cognition, not a separate function” (p. 299). There would be several kinds of nonperceptual awareness, for example “estimating or predicting without the extracting of an invariant” (Reed, 1988, p. 299, quoting Gibson's notes from 1977).

These quotes suggest that the mode distinction and the inferential mode have a place in the Gibsonian tradition. However, in addition to Gibson's (1966) conditions under which “guessing” or “estimating” occur, inferential mode functioning could also occur when specifying variables (invariants) are available but difficult to discriminate.

Nonspecifying variables: problem and possible solutions

The direct-perception approach holds that perception is veridical under ecologically relevant conditions. Information is specific to environmental properties (if relevant constraints prevail), and perception is the detection of information (Gibson, 1966, 1979; see also Runeson, 1988). Researchers in

the neo-Gibsonian tradition (e.g., Burton & Turvey, 1990; Michaels & Carello, 1981; cf. Cutting, 1982) assume that there is a one-to-one mapping not only between environmental properties and information, but also that there is a one-to-one mapping between perception and information. As a consequence, it is expected that perceivers who intend to perceive the same property will rely on the same specifying informational variable (cf. Withagen & Chemero, 2009). However, several recent studies have found that observers, particularly novices, differ in which variable they rely on in the same task, and that they thus in some cases rely on nonspecifying variables (e.g., Jacobs, Runeson, & Michaels, 2001; Michaels & de Vries, 1998). If observers rely on nonspecifying variables, perception can be said to be non-veridical and erroneous, which goes against the assumption of realism which the direct-perception notion articulates (e.g., Turvey, Shaw, Reed, & Mace, 1981).

Michaels and Carello (1981) argued that the label "error" is not justified from an ecological perspective when the phylogeny and ontology of the animal is considered. "An animal is not misperceiving (or misacting) if it is doing what it is supposed to do (has evolved or learned to do), the apparent 'success' of the act aside" (p. 96; cf. Cutting, 1982). To solve what they called the "apparent paradox of learning and realism", Jacobs and Michaels (2002) argued that changes in variable use during learning are fast relative to changes in normally prevailing constraints. They concluded that "the assumption of realism cannot be maintained if one considers short-scale phenomena", and that "perceptual systems cannot be said to exploit nonspecifying variables if the minimal time units are taken with respect to the longer scale of realism" (p. 136). Thus, they argued that the principles of perceptual learning and principles of realism (perceptual veridicality) should be evaluated at different time scales.

Also Withagen and Chemero (2009; Withagen, 2004) addressed the question of veridicality vs. reliance on nonspecifying variables. They claimed that, from an evolutionary perspective, it is unwise to expect minimal variation in what variables individuals rely upon. Moreover, it is not always necessary to rely on specifying variables because nonspecifying variables that correlate highly with environmental properties may be "good enough" for the animal to survive (see also Gibson, 1966, p. 286). However, relying on nonspecifying variables would lead to a "weak epistemic contact" between the perceiver and the environment (Withagen, 2004, p. 249).

Withagen (2004) denied that reliance on, and usage of, nonspecifying variables could entail inferential processes, which Runeson et al. (2000) did suggest. However, Withagen interpreted Runeson et al.'s suggestion of an inferential mode as implying that the environment was perceived indirectly, via a representation (p. 243). However, what Runeson et al. proposed, professed in this thesis as well, was two modes of apprehension and not two modes of perception. Jacobs and Michaels (2002), on the other hand, dis-

cussed inferences, and the inferential mode, in terms of judgments, which is more akin to at least the present formulation of the inferential mode. They considered whether use of nonspecifying variables would reflect inferences or beliefs rather than perception. This would be in agreement with the commitment to realism and perceptual veridicality because it "liberates perception from the errors that follow from the apparent use of nonspecifying variables" (p. 132). "Instead of concluding that the perception of relative mass was based on this nonspecifying variable [Exit-Speed] and, thus, that the perception of relative mass was nonveridical, one could also conclude that the novices veridically perceived the considered speed difference and that they mistakenly based the relative mass judgments on the veridical speed perception." (p. 132) Reasons for improvements in the task could then be sought "at the level of inferences from perception to judgments".

However, Jacobs and Michaels (2002) pointed out that if the relation between perception and judgment could explain empirical findings, claims about the relation between perception and environment would be unfalsifiable. Nevertheless, what is maintained in this thesis is that to leave out a role of inferential processes and a distinction between perception and judgments (particularly in tasks that do not require perception-action functioning, cf. Carello et al., 1989; Heft, 1993) would unnecessarily narrow the scope of ecological psychology, and perhaps put a too heavy load on those who seek to explain empirical findings *only* in relations between perception and environment.

Two functions of the inferential mode

One function of the inferential mode would be to make judgments of a property that is currently not perceptually available. That which is perceived is then not the ultimately sought-after property, but it is instead other properties, which are used as cues or clues that might lead to the sought-after property through some kind of inferences. Here, cues are the "indirect evidence" (cf. Shaw, 2003) that are linked by inferences to what is earlier known by perceiving the environment.

Another function of the inferential mode could be to help *direct attention* to properties that may function as cues. Jacobs and Michaels (2002; Shaw & Kinsella-Shaw, 1988) pointed out that intentions influence what variables perception relies on. In experiments, it is assumed that instructions will determine the perceivers' intentions. More specifically, it is assumed that the perceiver intends to perceive what they are instructed to judge. What is suggested here is that inferences, or other cognitive processes, may incite variations in intentions, and thus attention, under new or unusual circumstances. Inferences would then function to direct attention to information about properties that could serve as cues to a target property, in particular in cases when the target property is hard to perceive.

For example, in the relative mass task, one could presume that the observer intends to make good judgments of relative mass. However, this does not necessarily mean that he or she intends to perceive the relative mass. Perhaps the observer has difficulties in discriminating the specifying variable, or he or she might even not believe that there could be a specifying variable, or that relative mass is perceivable. Then he or she might intend to perceive another property, which is taken to lead to the relative mass by inference. The intention to make good judgments would not change, but the intended perception would change.

Constraints and inferences

In Study I, it was found that some participants relied on the so-called Sweep-Speed variable. This was unexpected considering that Sweep-Speed is mechanically independent of mass ratio, and, in the set of collisions used, uncorrelated with mass ratio. However, sweep-speed components contribute to the speeds of the objects and there is a considerable correlation between the Sweep-Speed and Exit-Speed variables in the set of collision used. The reliance on Sweep-Speed, together with the heavy reliance on Exit-Speed in particular for novices, suggests that "speediness" is a relevant property when judging the relative mass. But did speediness give a perceptual impression of lightness, or was speediness used as a cue?

Perhaps the answer lies in the relation between the used variable and the sought-after property. Considering naturally occurring constraints, what is the relation between speediness and mass? According to physical laws, lightness and speediness (in the sense of quickness in changes of motions) are generally coupled, and they probably often co-occur. But is the coupling so strong that the perceptual system has developed or learned to take advantage of such a constraint? Conversely, is it plausible that the observer relies on the variable *without* a complementary rule? Perhaps experiments that require perception-action responses without judgments (cf. Carello et al., 1989; Heft, 1995) could reveal whether a putative speediness-lightness constraint is exploited by the perceptual system or not. However, as judgments and inferences would ultimately be contingent on experiences of the environment, and hence on naturally occurring constraints, such an experimental paradigm would need careful considerations.

Another possible way to try to distinguish perception from inferential judgments could be to consider shifts in variables usage. As the perceptual system is adapted to fairly stable constraints, abrupt shifts might be explained by the observer's varying intention to perceive properties that can act as cues. That is, although the overall intention would be to perform well in a task, intentions to seek out cues may lead to abrupt shifts in variable usage.

Conclusion

To acknowledge a role of inferential processes, guesses, estimates, and judgments in daily life, and perhaps particularly in experimental tasks, may help to preserve the notion of realism and the veridicality of perception. Inferential processes should be considered as an alternative explanation in cases when observers rely on nonspecifying variables. Moreover, it should not be ruled out that there is interplay between perception and inferential processes in tasks that on a first blush seem to require only perception. To study the two types of functioning, it might be fruitful to employ fairly simple task environments (at least initially), to contrast perception-action responses with judgments, to consider natural constraints, and to examine shifts in variable usage. It might even be fruitful to create a framework that combines Gibson's notion of direct perception and realism, with Brunswik's probabilism, using methods from both traditions (cf. Vicente, 2003; Kirlik, 2009). In such an extended and unified ecological framework, (direct-) perception would be the primordial and first-hand function, and inferential mode functioning would be a complement aiding humans in their search for meaning.

In all, despite several discouraging results of the studies in this thesis, it is maintained that the notion of two modes of apprehension is worth further investigation and that this distinction has a place within an ecological framework.

Acknowledgements

I would like to express my gratitude towards Sverker Runeson for being my supervisor and mentor, for friendship, and for sharing his knowledge and visions on ecological psychology. I also thank the Department of Psychology, Erik Börjesson, Peter Juslin, Leo Poom, Staffan Sohlberg, and all former and present staff at the C-building. I thank Gästrik-Hälsinge Nation for financial support. And, huge thanks to Maria Håkansson, Erika Lundgren, and Leif-Jöran Olsson.

Research was supported by grants to Sverker Runeson from the *Royal Swedish Academy of Science (KVA)*, the *Swedish Research Council (VR)*, and the *Bank of Sweden Centennial Foundation (RJ)*.

References

- Allik, J. & Konstabel, K. (2005). G. F. Parrot and the theory of unconscious inferences. *Journal of the History of the Behavioral Sciences*, 41, 317-330.
- Amemiya, T. (1981). Qualitative response models: A survey. *Journal of Economic Literature*, 19, 1483-1536.
- Anderson, J. R. (1982). Acquisition of cognitive skill. *Psychological Review*, 89, 369-406.
- Baranski, J. V., & Petrusic, W. M. (1994). The calibration and resolution of confidence in perceptual judgments. *Perception and Psychophysics*, 55, 412-428.
- Baranski, J. V., & Petrusic, W. M. (1999). Realism of confidence in sensory discrimination. *Perception and Psychophysics*, 61, 1369-1383.
- Begleiter, H., Porjesz, B., Chou, C. L., & Aunon, J. I. (1983). P3 and stimulus incentive value. *Psychophysiology*, 20, 338-350.
- Bernstein, N. (1967). *The coordination and regulation of movements*. New York: Pergamon Press.
- Bingham, G. P. (2000). Events (like objects) are things, can have affordance properties, and can be perceived. *Ecological Psychology*, 12, 29-36.
- Bingham, G. P., & Pagano, C. C. (1998). The necessity of a perception-action approach to definite distance perception: Monocular distance perception to guide reaching. *Journal of Experimental Psychology: Human Perception & Performance*, 24, 145-168.
- Björkman, M., Juslin, P., & Winman, A. (1993). Realism of confidence in sensory discrimination: The underconfidence phenomenon. *Perception and Psychophysics*, 54, 75-81.
- Blais, A.-R., Thompson, M. M., & Baranski, J. V. (2005). Individual differences in decision processing and confidence judgments in comparative judgment tasks: The role of cognitive styles. *Personality and Individual Differences*, 38, 1701-1713.
- Braunstein, M. L. (2002). A better understanding of inference can reconcile constructivist and direct theories. *Behavioral and Brain Sciences*, 25, 99.
- Brookhuis, K. A., Mulder, G., Mulder, L. J. M., Gloerich, A. B. M., van Dellen, H. J., van der Meere, J. J., & Ellermann, H. (1981). Late positive components and stimulus evaluation time. *Biological Psychology*, 13, 107-124.
- Bruner, J. S. (1957). On perceptual readiness. *Psychological Review*, 64, 123-52.
- Brunswik, E. (1955). "'Ratiomorphic' models of perception and thinking. *Acta Psychologica*, 11, 108-109.
- Brunswik, E. (1956). Perception and the representative design of psychological experiments. Berkeley: University of California Press.
- Brunswik, E. (1966). Reasoning as a universal behavior model and a functional differentiation between "perception" and "thinking". Read at the International Congress of Psychology in Montreal, 1954. Published in K. R. Hammond, *The Psychology of Egon Brunswik*, New York: Holt, Rinehart, & Winston.

- Burton, G. & Turvey, M. T. (1990). Perceiving the lengths of rods that are held but not wielded. *Ecological Psychology*, 2, 295-324.
- Chemero, A. (2003). Information for perception and information processing. *Minds and Machines*, 13, 577-588.
- Cohen, A. L. (2006). Contributions of invariants, heuristics, and exemplars to the visual perception of relative mass. *Journal of Experimental Psychology: Human Perception and Performance*, 32, 574-598.
- Comerchero, M. D. & Polich, J. (1999). P3a and P3b from typical auditory and visual stimuli. *Clinical Neurophysiology*, 110, 24-30.
- Cutting, J. E. (1982). Two ecological perspectives: Gibson vs. Turvey and Shaw. *American Journal of Psychology*, 95, 199-222.
- Donchin, E. (1981). Surprise!... Surprise? *Psychophysiology*, 18, 493-513.
- Donchin, E., & Coles, M. G. H. (1988). Is the P300 component a manifestation of context updating? *Behavioral and Brain Sciences*, 11, 357-374.
- Dreyfus, H. L., Dreyfus, S. E. (1986) *Mind over machine: the power of human intuition and expertise in the era of the computer*. New York, NY: Free Press.
- Epstein, W. (1995). The metatheoretical context. In W. Epstein & S. Rogers (Eds.), *Perception of space and motion* (pp. 1-20), San Diego, CA: Academic Press.
- Erev, I., Wallsten, T. S., & Budescu, D. V. (1994). Simultaneous over- and underconfidence: The role of error in judgment processes. *Psychological Review*, 101, 519 - 527.
- Ericsson, A. K., & Simon, H. A. (1980). Verbal reports as data. *Psychological Review*, 87, 215-251.
- Fabiani, M., Gratton, G., Karis, D., & Donchin, E. (1987). The definition, identification, and reliability of measurements of the P300 component of the event-related brain potential. In P.K. Ackles, J.R. Jennings, and M.G.H. Coles (Eds.), *Advances in Psychophysiology*. Greenwich, CT: JAI Press.
- Fajen, B. R., & Devaney, M. C. (2006). Learning to control collisions: the role of perceptual attunement and action boundaries. *Journal of Experimental Psychology: Human Perception and Performance*, 32, 300 - 313.
- Ferrell, W. R. (1995). A model for realism of confidence judgments: Implications for underconfidence in sensory discrimination. *Perception and Psychophysics*, 57, 246-254.
- Fitts, P. M. (1964). Perceptual-motor skill learning. In A. W. Melton (Ed.), *Categories of human learning* (pp. 243-285). New York: Academic Press.
- Fodor, J. A., & Pylyshyn, Z. (1981). How direct is visual perception? Some reflections on Gibson's 'Ecological Approach'. *Cognition*, 9, 139-196.
- Fowler, C. A., & Turvey, M. T. (1978). Skill acquisition: An event approach with special reference to searching for the optimum of a function of several variables. In G. Stelmach (Ed.), *Information processing in motor control and learning* (pp. 1-40). New York: Academic Press.
- Gallagher, S. (2002). Experimenting with introspection. *Trends in Cognitive Sciences*, 6, 374-375.
- Gibson, J. J. (1966). *The senses considered as perceptual systems*. Boston, MA: Houghton Mifflin.
- Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston, MA: Houghton Mifflin.
- Gibson, J. J., & Gibson, E. J. (1955). Perceptual learning: Differentiation or enrichment? *Psychological Review*, 62, 32-41.
- Gigerenzer, G., Hoffrage, U., & Kleinbölting, H. (1991). Probabilistic mental models: A Brunswikian theory of confidence. *Psychological Review*, 98, 506-528.

- Gilden, D. L. (1991). On the origin of dynamical awareness. *Psychological Review*, 98, 554-568.
- Gilden, D. L., & Proffitt, D. R. (1989). Understanding collision dynamics. *Journal of Experimental Psychology: Human Perception and Performance*, 15, 372-383.
- Gilden, D. L., & Proffitt, D. R. (1994). Heuristic judgment of mass ratio in two-body collisions. *Perception and Psychophysics*, 56, 708-720.
- Hajnal, A., Grocki, M., Jacobs, D. M., Zaal, F. T. J. M., Michaels, C. F. (2006). Mode transition and change in variable use in perceptual learning. *Ecological Psychology*, 18, 67-91.
- Hammond, K. R. (1966). *The psychology of Egon Brunswik*. New York: Holt, Rinehart, & Winston.
- Hammond, K. R., & Stewart, T. R. (2001). *The essential Brunswik*. New York: Oxford University Press.
- Hatfield, G. (1988). Representations and content in some (actual) theories of perception. *Studies in History and Philosophy of Science*, 19, 175-214.
- Hatfield, G. (1990). Gibsonian representations and connectionist symbol processing: Prospects for unification. *Psychological Research*, 52, 243-252.
- Hecht, H. (1996). Heuristics and invariants in dynamic event perception: Immunized concepts or non-statements? *Psychonomic Bulletin and Review*, 3, 61-70.
- Hecht, H. (2000). The failings of three event perception theories. *Journal of the Theory of Social Behaviour*, 30, 1-25.
- Heft, H. (1993). A methodological note on overestimates of reaching distance: distinguishing between perceptual and analytical judgments. *Ecological Psychology*, 5, 255-271.
- Helmholtz, H. von (1896). *Handbook of physiological optics*. Hamburg, Leipzig: Leopold Voss.
- Jack, A. I., & Roepstorff, A. (2002). Introspection and cognitive brain mapping: from stimulus-response to script-report. *Trends in Cognitive Sciences*, 6, 333-339.
- Jack, A. I., & Shallice, T. (2001). Introspective physicalism as an approach to the science of consciousness. *Cognition*, 79, 161-196.
- Jacobs, D. M., & Michaels, C. F. (2001). Individual differences and the use of non-specifying variables in learning to perceive distance and size: Comments on McConnell, Muchisky, and Bingham (1998). *Perception and Psychophysics*, 63, 563 - 571.
- Jacobs, D. M., & Michaels, C. F. (2002). On the apparent paradox of learning and realism. *Ecological Psychology*, 14, 127-139.
- Jacobs, D. M., & Michaels, C. F. (2007). Direct learning. *Ecological Psychology*, 19, 321-349.
- Jacobs, D. M., Michaels, C. F., & Runeson, S. (2000). Learning to perceive the relative mass of colliding balls: The effects of ratio-scaling and feedback. *Perception and Psychophysics*, 62, 1332-1340.
- Jacobs, D. M., Michaels, C. F., Zaal, F. T. J. M., & Runeson, S. (2001). Developing expertise: Mode transition or mere change in variable use? In G. A. Burton & R. C. Schmidt (Eds.): *Studies in Perception and Action VI* (pp. 181-184). Mahwah, NJ: Lawrence Erlbaum Associates.
- Jacobs, D. M., Runeson, S., & Andersson, I. E. K. (2001). Reliance on constraints means detection of information. *Behavioral and Brain Sciences*, 24, 679-680.
- Jacobs, D. M., Runeson, S., & Michaels, C. F. (2001). Learning to perceive the relative mass of colliding balls in globally and locally constrained task ecologies. *Journal of Experimental Psychology: Human Perception and Performance*, 27, 1019-1038.

- Johnson, R. (1988). The amplitude of the P300 component of the event-related potential: Review and synthesis. In P. K. Ackles, J. R. Jennings, & M. G. H. Coles (Eds.) *Advances in psychophysiology* (Vol. 3, pp. 69-137). Greenwich, CT: JAI Press, Inc.
- Juslin, P. (1994). The overconfidence phenomenon as a consequence of informal experimenter-guided selection of almanac items. *Organizational Behavior and Human Decision Processes*, *57*, 226-246.
- Juslin, P., & Olsson, H. (1997). Thurstonian and Brunswikian origins of uncertainty in Judgment: A sampling model of confidence in sensory discrimination. *Psychological Review*, *104*, 344-366.
- Juslin, P., Olsson, H., & Björkman, M. (1997). Brunswikian and Thurstonian origins of bias in probability assessment: On the interpretation of stochastic components of judgment. *Journal of Behavioral Decision Making*, *10*, 189-209.
- Juslin, P., Olsson, H., & Winman, A. (1998). The calibration issue: Theoretical comments on Suantak, Bolger, and Ferrell (1996). *Organizational Behavior and Human Decision Processes*, *73*, 3-26.
- Juslin, P., Winman, A., & Olsson, H. (2000). Naive empiricism and dogmatism in confidence research: A critical examination of the hard-easy effect. *Psychological Review*, *107*, 384-396.
- Kellogg, R. T. (1982). When can we introspect accurately about mental processes? *Memory and Cognition*, *10*, 141-144.
- Kersten, D., Mamassian, P., & Yuille, A. (2004). Object perception as Bayesian inference. *Annual Review of Psychology*, *55*, 271-304.
- Kirlik, A. (2009). Brunswikian resources for event-perception research. *Perception*, *38*, 376-398.
- Klayman, J., Soll, J. B., Gonzalez-Vallejo, C., & Barlas, S. (1999). Overconfidence? It depends on how, what and whom you ask. *Organizational Behavior and Human Decision Processes*, *79*, 216-247.
- Kleitman, S., & Stankov, L. (2001). Ecological and person-oriented aspects of metacognitive processes in test-taking. *Applied Cognitive Psychology*, *15*, 321-341.
- Knill, D. C., Kersten, D., & Yuille, A. (1996). Introduction: A Bayesian formulation of visual perception. In D. C. Knill and W. Richards (Eds.), *Perception as Bayesian inference* (pp. 1-21), Cambridge, UK: Cambridge Univ. Press.
- Kok, A. (1986). Effects on degradation of visual stimuli on components of the event-related potential (ERP) in Go/Nogo reaction tasks. *Biological Psychology*, *23*, 21-38.
- Kok, A., (2001). On the utility of P3 amplitude as a measure of processing capacity. *Psychophysiology*, *38*, 557-577.
- Kotchoubey, B. (2002). Do event-related brain potentials manifest mental (cognitive) processes? *Journal of Psychophysiology*, *16*, 129-149.
- Kotchoubey, B. (2006). Event -related potentials, cognition, and behavior: A biological approach. *Neuroscience and Biobehavioral Reviews*, *30*, 42-65.
- Kozlowski, L. T., & Cutting, J. E. (1977). Recognizing the sex of a walker from a dynamic point-light display. *Perception and Psychophysics*, *21*, 575-580.
- Kramer, A., Schneider, W, Fisk, A. & Donchin, E. (1986). The effects of practice and task structure on components of the event-related brain potential. *Psychophysiology*, *23*, 33-47.
- Kreegipuu, K., & Runeson, S. (1999). Becoming competent through the perceiver's eye. In M. A. Grealy & J. A. Thomson (Eds.), *Studies in Perception and Action V: Tenth International Conference on Perception and Action* (pp.20-23), Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

- Kreegipuu, K., & Runeson, S (2000). *The subjective aspect of achieving perceptual competence*. Unpublished manuscript.
- Kubovy, M., & Epstein, W. (2001). Internalization: A metaphor we can live without. *Behavioral and Brain Sciences*, 24, 618-625.
- Kubovy, M., Epstein, W., & Gepshtein, S. (2003). Foundations of visual perception. In A. F. Healy and R. W. Proctor (Eds.), *Handbook of psychology, Vol 4*. (pp 87-119), Hoboken, NJ: John Wiley & Sons, Inc.
- Kvidera, S., & Koutstaal, W. (2008). Confidence and decision type under matched stimulus conditions: overconfidence in perceptual but not in conceptual decisions. *Journal of Behavioral Decision Making*, 21, 253-281.
- Lee, D. N., & Aronson, E. (1974). Visual proprioceptive control of standing in human infants. *Perception and Psychophysics*, 15, 529-532.
- Lichtenstein, S., & Fischhoff, B. (1977). Do those who know more also know more about how much they know? The calibration of probability judgments. *Organizational Behavior and Human Performance*, 20, 159 - 183.
- Lutz, A., Lachaux, J. P., Martinerie, J., & Varela, F. J. (2002). Guiding the study of brain dynamics by using first-person data: Synchrony patterns correlate with ongoing conscious states during a simple visual task. *Proceedings of the National Academy of Sciences U. S. A.*, 99, 1586-1591.
- Magliero, A., Bashore, T., Coles, M. G. H., & Donchin, E. (1984). On the dependence of P300 latency on stimulus evaluation processes. *Psychophysiology*, 21, 171-186.
- Marr, D. (1982). *Vision*. San Francisco: W. H. Freeman.
- McClelland, A. G. R., & Bolger, F. (1994). The calibration of subjective probabilities: Theories and models 1980-1993. In G. Wright & P. Ayton (Eds.), *Subjective probability* (pp. 453-482). Chichester, England: Wiley.
- Michaels, C. F., & Arzamarski, R., Isenhower, R. W., Jacobs, D. M. (2008). Direct learning in dynamic touch. *Journal of Experimental Psychology: Human Perception and Performance*, 34, 944-957.
- Michaels, C. F., & Beek, P. (1995). The state of ecological psychology. *Ecological Psychology*, 7, 259-278.
- Michaels, C. F., & Carello, C. (1981). *Direct Perception*. Engelwood Cliffs, NJ: Prentice Hall.
- Michaels C. F., & de Vries, M. M. (1998). Higher order and lower order variables in the visual perception of relative pulling force. *Journal of Experimental Psychology: Human Perception and Performance*, 24, 526-546.
- Nisbett, R. E., & Wilson, T. D. (1977). Telling more than we can know: Verbal reports on mental processes. *Psychological Review*, 84, 231-259.
- Norman, J. (2002). Two visual systems and two theories of perception: An attempt to reconcile the constructivist and ecological approaches. *Behavioral and Brain Sciences*, 25, 73-144.
- Okita, T., Wijers, A. A., Mulder, G., & Mulder, L. J. M. (1985). Memory-search and visual spatial attention: An event-related potential analysis. *Acta Psychologica*, 60, 263-292.
- Olsson, H., & Winman, A. (1996). Underconfidence in sensory discrimination: The interaction between experimental setting and response strategies. *Perception and Psychophysics*, 58, 374-382.
- Palmer, B., Nasman, V. T., & Wilson, G. F. (1994). Task decision difficulty: effects on ERPs in a same-different letter classification task. *Biological Psychology*, 38, 199-214.

- Petrusic, W. M., & Baranski, J. V. (1997). Context, feedback, and the calibration and resolution of confidence in perceptual judgments. *The American Journal of Psychology*, *110*, 543-572.
- Pfefferbaum, A., Ford, J. M., Johnson, R., Jr., Wenegrat, B., & Kopell, B. S. (1983). Manipulation of P3 latency: Speed vs accuracy instructions. *Electroencephalography and Clinical Neurophysiology*, *55*, 188-197.
- Polich, J. (1987). Task difficulty, probability, and inter-stimulus interval as determinants of P300 from auditory stimuli. *Electroencephalography and Clinical Neurophysiology*, *68*, 311-320.
- Pritchard, W. S. (1981). Psychophysiology of P300. *Psychological Bulletin*, *89*, 506-540.
- Proffitt, D. R., & Gilden, D. L. (1989). Understanding natural dynamics. *Journal of Experimental Psychology: Human Perception & Performance*, *15*, 384-393.
- Pylyshyn, Z. (1999). Is vision continuous with cognition? The case for cognitive impenetrability of visual perception. *Behavioral and Brain Sciences*, *22*, 341-423.
- Rayner, S., & Riding, R. (1997). Towards a categorisation of cognitive styles and learning styles. *Educational Psychology*, *17*, 5-27.
- Reed, E. S. (1988). *James J. Gibson and the psychology of perception*. Yale University Press.
- Rock, I. (1983). *The logic of perception*. Cambridge, MA: MIT Press.
- Rogers, S. (2000). The emerging concept of information. *Ecological Psychology*, *12*, 365-375.
- Rugg, M. D., & Coles, M. G. H. (1995). *Electrophysiology of the mind. Event-related potentials and cognition*. Oxford: Oxford University Press.
- Runeson, S. (1974). Constant velocity—Not perceived as such. *Psychological Research*, *37*, 3-23.
- Runeson, S. (1983). *On visual perception of dynamic events*. (Acta Universitatis Upsaliensis: Studia Psychologica Upsaliensia, No. 9). Uppsala, Sweden: University of Uppsala. (Original work published 1977)
- Runeson, S. (1977). On the possibility of 'smart' perceptual mechanisms. *Scandinavian Journal of Psychology*, *18*, 172-179.
- Runeson, S. (1988). The distorted room illusion, equivalent configurations, and the specificity of static optic arrays. *Journal of Experimental Psychology: Human Perception and Performance*, *14*, 295-304.
- Runeson, S. (1989). A note on the utility of ecologically incomplete invariants. *International Society for Ecological Psychology, Newsletter*, *4*, 6-9.
- Runeson, S. (1994). Psychophysics: The failure of an elementaristic dream. *Behavioral and Brain Sciences*, *17*, 761-763.
- Runeson, S. (1994). Perception of biological motion: The KSD-principle and the implications of a distal versus proximal approach. IN G. Jansson, S. S. Bergström, & W. Epstein (Eds.), *Perceiving events and objects* (pp. 383-405). Hillsdale, NJ: Erlbaum.
- Runeson, S. (1995). Support for the cue-heuristic model is based on suboptimal observer performance: Response to Gilden & Proffitt (1994). *Perception and Psychophysics*, *57*, 1262-1273.
- Runeson, S., & Frykholm, G. (1981). Visual perception of lifted weight. *Journal of Experimental Psychology: Human Perception and Performance*, *7*, 733-740.
- Runeson, S., & Frykholm, G. (1983). Kinematic specification of dynamics as an informational basis for person and action perception: Expectation, gender recognition, and deceptive intention. *Journal of Experimental Psychology: General*, *112*, 585-615.

- Runeson, S., Juslin, P., & Olsson, H. (2000). Visual perception of dynamic properties: Cue heuristics versus direct-perceptual competence. *Psychological Review*, *107*, 525-555.
- Runeson, S., & Vedeler, D. (1993). The indispensability of precollision kinematics in the visual perception of relative mass. *Perception and Psychophysics*, *53*, 617-632.
- Shaw, R. E. (2003). The agent-environment interface: Simon's indirect or Gibson's direct coupling? *Ecological Psychology*, *15*, 37-106.
- Shaw, R. E., & Kinsella-Shaw, J. (1988). Ecological mechanics: a physical geometry for intentional constraints. *Human Movement Science*, *7*, 155-200.
- Shepard, R. N. (2001). Perceptual-cognitive universals as reflections of the world. *Behavioral and Brain Sciences*, *24*, 581-601.
- Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory. *Psychological Review*, *84*, 127-189..
- Stankov, L. (1998). Calibration curves, scatterplots and the distinction between general knowledge and perceptual tasks. *Learning and Individual Differences*, *10*, 29-50.
- Stankov, L., & Crawford, J. D. (1996). Confidence judgments in studies of individual differences. *Personality and Individual Differences*, *21*, 971-986.
- Stankov, L., & Crawford, J. D. (1997). Self-confidence and performance on tests of cognitive abilities. *Intelligence*, *25*, 93-109.
- Stoffregen, T. A. (1993). "Natural", "real", and the use of non-physical displays in perception-action research. *ISEP Newsletter*, *6*, 4-9.
- Suantak, L., Bolger, F., & Ferrell, W. R. (1996). The hard-easy effect in subjective probability calibration. *Organizational Behavior and Human Decision Processes*, *67*, 201-221
- Subbotin, V. (1996). Outcome feedback effects on under- and overconfident judgments (general knowledge tasks). *Organizational Behavior and Human Decision Processes*, *66*, 268-276.
- Summerfield, C., Jack, A. I., & Burgess, A. P. (2002). Induced gamma activity is associated with conscious awareness of pattern masked nouns. *International Journal of Psychophysiology*, *44*, 93-100.
- Turvey, M. T., Shaw, R. E., Reed, E. D., & Mace, W. M. (1981). Ecological laws of perceiving and acting: In reply to Fodor and Pylyshyn. *Cognition*, *9*, 237-304.
- Twardy, C. R. & Bingham, G. P. (1999) Role of energy conservation in event perception. In M. A. Grealy & J. A. Thomson (Eds.) *Studies in Perception and Action V*, Mahwah, NJ: Lawrence Erlbaum Associates
- Vereijken, B., van Emmerik, R. E. A., Whiting, H. T. A., & Newell, K. M. (1992). Free(z)ing degrees of freedom in skill acquisition. *Journal of Motor Behavior*, *24*, 133-142.
- Verleger, R. (1988). Event-related potentials and memory: A critique of the context updating hypothesis and an alternative interpretation of P3. *Behavioral and Brain Sciences*, *11*, 343-356.
- Wagemans, J. (1990). "Smart" mechanisms emerging from cooperation and competition between modules. *Psychological Research*, *52*, 181-196.
- Wagman, J. B., Shockley, K., Riley, M. A., & Turvey, M. T. (2001). Attunement, calibration, and exploration in fast haptic perceptual learning. *Journal of Motor Behavior*, *33*, 323 - 327.
- Warren, W. H. (2005). Direct perception: The view from here. *Philosophical Topics*, *33*, 335-361.

- White, P. A. (1980). Limitations on verbal reports of internal events: A refutation of Nisbett and Wilson and of Bern. *Psychological Review*, *87*, 105-112.
- White, P. A. (1988). Knowing more about what we can tell: 'Introspective access' and causal report accuracy 10 years later. *British Journal of Psychology*, *79*, 13-45.
- Wijers, A. A., Otten, L. J., Feenstra, S., Mulder, G., & Mulder, L. J. (1989). Brain potentials during selective attention, memory search, and mental rotation. *Psychophysiology*, *26*, 452-467.
- Wilson, T. D. (2002). *Strangers to ourselves: Discovering the adaptive unconscious*. Cambridge MA: Harvard University Press.
- Winman, A., & Juslin, P. (1993). Calibration of sensory and cognitive judgments: Two different accounts. *Scandinavian Journal of Psychology*, *34*, 135-148.
- Withagen, R. (2004). The pickup of nonspecifying variables does not entail indirect perception. *Ecological Psychology*, *16*, 237-253.
- Withagen, R. & Chemero, A. (2009). Naturalizing perception. *Theory & Psychology*, *19*, 363-389.
- Withagen, R., & Michaels, C. F. (2004). Transfer of calibration in length perception by dynamic touch. *Perception & Psychophysics*, *66*, 1282-1292.
- Withagen, R., & Michaels, C. F. (2005). The roles of feedback information for calibration and attunement in perceiving length by dynamic touch. *Journal of Experimental Psychology: Human Perception and Performance*, *31*, 1379 -1390.
- Witkin, H. A., Moore, C. A., Goodenough, D. R., & Cox, P. W. (1977). Field-dependent and field-independent cognitive styles and their educational implications. *Review of Educational Research*, *47*, 1-64.
- Yates, J. F. (1990). *Judgment and decision making*. Englewood Cliffs, NJ: Prentice Hall.

Acta Universitatis Upsaliensis

*Digital Comprehensive Summaries of Uppsala Dissertations
from the Faculty of Social Sciences 52*

Editor: The Dean of the Faculty of Social Sciences

A doctoral dissertation from the Faculty of Social Sciences, Uppsala University, is usually a summary of a number of papers. A few copies of the complete dissertation are kept at major Swedish research libraries, while the summary alone is distributed internationally through the series Digital Comprehensive Summaries of Uppsala Dissertations from the Faculty of Social Sciences. (Prior to January, 2005, the series was published under the title "Comprehensive Summaries of Uppsala Dissertations from the Faculty of Social Sciences".)

Distribution: publications.uu.se
urn:nbn:se:uu:diva-108214



ACTA
UNIVERSITATIS
UPSALIENSIS
UPPSALA
2009