3. GENERAL DISCUSSION

3.1 Overview

The general discussion focuses mainly on the interpretations of the results from the empirical part. The goal here is to integrate these results into a lifespan perspective that views the development of cognitive abilities as multidimensional and multi-directional, and as embedded in a framework that considers antecedents, correlates, and consequences of individual differences in cognitive functioning. Results are also discussed with an emphasis on methodological aspects and the advantages of using the proposed NF representation. Furthermore, results from a Monte Carlo study are used to derive recommendations for designing new correlational studies on disentangling general and specific effects.

3.2 Multidimensionality of Cognitive Abilities in Old and Very Old Age

Results from applying the NF model to the BASE data showed that each specific factor contributed substantially and significantly to the description of the multivariate space spanned by the 14 cognitive tasks. A model specifying only a general factor yielded unacceptable fit. Even though the factor structure was much more dominated by the general factor than in a comparison sample of younger adults, one still needs a multidimensional model to appropriately represent individual differences in cognitive abilities above age 70. Projecting these individual differences onto a single dimension of a general factor led to an average loss of about one fifth of the reliable variance contained in the indicator variables, as indicated by the communalities of the factors. Comparing the total communality of the nested factors with the total communality of a model with oblique (i.e., correlated) first-order factors, however, indicated that both models explained about the same amount of variance. The strength of using the NF representation, therefore, did not lie in extracting more variance from the indicator variables than alternative approaches, namely the hierarchical or oblique factor models. Rather, it did partition the same total amount of variance into general and specific factors in a way that allowed the investigation of simultaneous relations of these factors to age and other external criterion variables.

The hierarchical model might have conceptual advantages (Mulaik & Quartetti, 1997), especially if factor models are interpreted in the context of the three-stratum theory of intelligence (Carroll, 1993). However, the simulations presented in this thesis show that it does not allow the simultaneous examination of the relations of all first- and second-order factors to external variables. The NF model capitalizes on the heterogeneity of the composition of general and specific variance in the indicator variables in a way that allows general and specific factor relations to external variables, such as age, to be disentangled. However, this property is bought at the price of additional parameters. Even though this seems to be a less desirable property of the NF model, it has to be recognized that the relative parsimony of the hierarchical model might often be reduced by the necessity of including correlated residual terms for pairs of variables. Such doublet factors also reduce parsimony and potentially absorb interesting variance that might be captured by the specific group factors in the NF model, as found in the analyses presented.

3.3 Multidirectionality of Age-Associated Differences

Relating the chronological age variable to the general and specific factors, either as an independent variable, covariate, or dependent variable, resulted in clear evidence for multidirectionality of age-associated differences in cognition. Similar cross-sectional evidence based on the same BASE data has already been reported with results showing significantly smaller negative age correlations of the composite measures of fluency and knowledge than those for the composites of reasoning, memory, and speed (Lindenberger & Baltes, 1997). Trying to explain these different age gradients by a model that uses only a general factor to explain age-associated differences led to the necessity of adding age correlations with the specific factors to adjust for overestimations of the age gradients of the fluency and knowledge tasks.

To incorporate a general factor in structural models, however, is just one methodological possibility to model the positive manifold among cognitive tasks. Furthermore, this approach does not necessarily represent the structure better than other models. An alternative representation would be to use an oblique factor model, in which the positive manifold is represented by the correlations among the first-order factors. With the cognitive battery of BASE, an oblique factor model was only slightly more parsimonious than the NF model, with $df = 68$ for the oblique model and $df = 64$ for the NF model. The oblique and the NF model could both explain an equal amount of variance in the indicator variables. However, relating the oblique model to the age variable led to worse fit and less age variance explained than using the NF model. In the NF model, the explicit representation of variance that is common to all tasks by a general factor—in combination with specific factors for each theoretical construct—seemed to better represent the multivariate age correlations of the BASE cognitive battery. Before discussing the interpretation of the general and specific factors and their age relations, some methodological aspects concerning the different ways of representing the age variable have to be considered.

3.3.1 Assumptions About the Age-Independent Structure in the Nested Factor Model

Previously, Lindenberger and Pötter (1998) have formally shown that the estimates of shared age-associated effects, which are central to correlational mediation models (i.e., age-associated effect in variable B could be explained by another mediational variable, A), depend on the age-independent partial correlation between the dependent and the mediator variable (i.e., the age-independent partial correlation between A and B). This causes serious problems when interpreting the estimates of shared age-associated variance as indicating mediation. Lindenberger and Pötter noted that their general critique also applies to cases when latent constructs are used as mediators. How does this critique relate to the use of nested factor models for investigating age-associated general and specific effects? The most important distinction between the NF models proposed here and the approaches discussed by Lindenberger and Pötter is that the latter address mediation models, where a causal ordering of the different theoretical constructs—such as age differences in processing speed leading to age differences in reasoning ability—is aimed at. Using correlational data, it is not possible to unambiguously identify unique patterns of causal priority linking different theoretical constructs, no matter whether the theoretical constructs are represented by observed variables or latent factors.

However, the goal of the analyses reported here has not been identifying a specific pattern of statistical causal priority that links a mediator to the various latent constructs. Rather, the goal has been to investigate how could both general and specific age-associated variance be represented in models describing the multivariate space of cognitive abilities. The models used for this purpose are based on a theoretical classification of cognitive tasks that distinguishes broad and narrow abilities. Such a classification has gained extensive empirical support (Carroll, 1993). This background allows a theory-guided separation of each variable's variance into components that are common to all tasks, components that are common to group factors of tasks defined a priori, and task-specific components. As discussed before, age can be related to these factors either as a predictor variable or as a covariate. In the first case, factors become correlated due to common age-associated effects. The age-independent structure, however, is still composed of orthogonal factors. Therefore, the *spuriousness* model of Lindenberger and Pötter (the case of no age-independent relation among the age-related variables, p. 220) applies here and the amount of age-related variance of one latent factor that is shared with another latent factor equals the square of the other factors correlation with age. In the case of using age as a covariate, the latent factors are orthogonal and, therefore, only independent age-associations of the different factors can be identified. There is no age variance shared among the latent factors and therefore questions about the amount of such shared variance cannot be addressed with this kind of model.

In sum, the nested factor model is proposed to provide an unbiased estimation of the relative contribution of general and specific factors to the representation of age variance or variance related to other external criterion variables. To this end, the nested factor model's utility is not limited by the criticisms raised against correlational mediation analyses.

3.3.2 Age as a Correlate or Dependent Variable

As explained in the theoretical part of this thesis, the factors in the age-as-a-predictor model are defined by the individual differences in initial level, ignoring individual differences that are due to mean effects of age. In the model with age as a covariate, these individual differences produced by mean effects of age, on the contrary, are represented by the factors. The strength of the age correlations indicates how much age variance these factors contain. It is argued here that neither of the two possibilities should be seen as generally more appropriate than the other for representing age differences. However, the model with age as a covariate allows the calculation of a summary measure that describes the strength of the relations between the nested factors and age. This can easily be done simply by squaring and summing up the age correlations of the nested factors, due to their property of being orthogonal to each other. How might the findings of the nested factors explaining independent portions of age variance be interpreted?

Models that specify only a general age-associated effect do imply that all age-related variance in a given set of cognitive tasks can be captured by a general factor. If this would be the case, individual differences in the specific factors should not contain further information about the age of the individuals beyond what is captured by the general factor. However, the fact that including specific factors could almost double the amount of explained age variance indicated that this was not the case. Rather, the specific factors did contain important additional information that is related to age. They captured the empirical fact that, *given a certain level of overall cognitive functioning as measured by the general factor*, older participants, on average, did relatively better on the knowledge and fluency tasks than the young-old participants in the BASE sample. When age is treated as a dependent variable, the information gained by including specific factors as predictors improves in the precision of the prediction.

3.4 Interpretation of General and Specific Factors and Their Age Relations

Is it possible to interpret the age-associated effects that were found for the general and specific factors as independent processes taking place in aging individuals? This question relates back to the discussion on the logical status of common factors. Just as it is not possible to interpret common factors as measures of the individuals' cognitive resources without making strong assumptions, it is also not viable to interpret age relations of those factors as processes that describe what is going on in individuals. Besides this already discussed ergodicity problem—which poses the question of whether the structure of interindividual differences is equivalent to the structure of intraindividual variability—and the general limitations of modeling mean age trends in cross-sectional data, there are several issues about the interpretation of the general and specific factors and their age relations that need to be discussed here in some detail. First, the interpretation of the common factors in terms of information-processing constructs is tied to the knowledge of the information-processing requirements of the cognitive tasks. Second, an interpretation of the general factor as indicating processing speed, as proponents of the processing speed theory might argue for, is problematic because of the existence of a specific factor of perceptual speed in addition to the general factor. Third, the counteracting negative general and positive specific age relations have to be interpreted in the context of a conceptualization that does not strictly separate the cognitive mechanics from the cognitive pragmatics at the level of behaviorally measured performance.

3.4.1 Information-Processing Components of the Cognitive Tasks

An interpretation of the age-relations of the general and specific factors as indicating general and specific processes would require a priori knowledge about which information-processing components are common to all tasks, and which components are only common to the subsets of tasks that load on the specific factors. This could only be achieved, however, if the tests were designed a priori to capture theory-based general and specific information-processing requirements. With the cognitive tasks used in BASE, this is clearly not the case. However, building on research that combines latent variable methods with tasks from the experimental cognitive tradition, it might be possible to get closer to information-processing resources than with the constructs of the psychometric tradition. The individual difference studies with latent factors of information-processing constructs that were cited in the theoretical part are examples of research that might help to integrate the perspectives on structure and process of cognitive aging phenomena. For example, one can think of studies trying to separate factors of sequential complexity from factors of coordinative complexity (Kliegl et al., 1995) or even general from specific factors of processing speed (Roberts & Stankov, 1999). Of special interest are also studies using task batteries with tasks of similar processing requirements but different content material (i.e., verbal and spatial) to further examine the differential age sensitivity of the two domains. Existing studies on this issue have not tried to disentangle domain-general from domain-specific factors but only compared age relations of the two domains (e.g., Jenkins et al., 2000; Lawrence, Myerson, & Hale, 1998; Myerson, Hale, Rhee, & Jenkins, 1999).

3.4.2 Processing Speed as a Mediating Construct

A question that follows from the earlier discussion of the separation of orthogonal general and specific factors as explanatory constructs of age-associated variance is whether the multivariate models presented in this thesis could also be used to test whether information processing speed can act as mediator of the age relations of other cognitive abilities. To test the processing speed theory with such multivariate models, however, it would be necessary to interpret the general factor as a pure factor of processing speed. The theoretical notion of this theory—that age differences on a set of cognitive tasks are mediated by a processing speed construct—could then be approached with the presented models.

On the one hand, the fact that the indicator variables of processing speed showed the highest loadings on the general factor somewhat speaks to such an interpretation. On the other hand, the finding that these tasks also contained reliable variance captured by a specific factor of speed, which was not significantly related to age, clearly argues against the interpretation of the general factor as a pure measure of processing speed. Therefore, the presented results imply a challenge for the processing speed theory not only because of the specific age relations in addition to a general effect, but also because the interpretation of the general factor as a general processing speed factor has no solid basis—as long as it is not clear why there is a part of the speed variables' variance that is shared with all other variables and another part that can be explained by a specific factor that is related only to the three speed variables and orthogonal to the general factor.

3.4.3 The Interplay of the Cognitive Mechanics and Pragmatics

The apparent split of age-associated effects into a negative effect for the general factor, non-significant relations of the specific reasoning, speed, and memory factors and positive age relations of specific factors of fluency and knowledge can be interpreted in the context of the mechanics and pragmatics of cognition. This conceptual framework predicts differential age gradients for the measured abilities depending on how much they tap the mechanics of information-processing versus the pragmatics of acquired knowledge. While this prediction has been supported by previous analyses (Lindenberger & Baltes, 1997), the present models do explicitly incorporate the fact that the mechanics and pragmatics are not independent of each other, but do share much common variance. There are several ways, however, to explain the common variance modeled by the general factor in the presented models.

First, factors that are not directly tied to the information-processing demands of the tasks, like motivation or fatigue, can be expected to influence performance on all cognitive tasks to some degree and, therefore, increase the variance of the general factor. Second, the observed correlations of different abilities might be due to common learning histories, transfer effects and developmental interactions as, for instance, proposed by the investment theory of intelligence (Cattell, 1971). For example, people who have trained their abilities in abstract thinking might also have put more effort into the acquisition of knowledge, which, in turn, might have been made even easier by the increased fluid capacities. Third, at the performance level measured by cognitive tasks of the psychometric tradition, it is not possible to define a clear-cut separation of crystallized knowledge versus mechanical abilities. The tasks used to measure reasoning, memory, or perceptual speed use content material where prior experiences and knowledge also play a role in determining overall task performance. One has to think of the relative contribution of such knowledge or experience as a rather continuous phenomenon across a broad selection of cognitive tasks. For the mechanic ability of reasoning, such a continuum might range from tasks with abstract content such as Raven's progressive matrices, to the *Practical problems* task used in BASE, for which knowledge probably plays a significant role. Furthermore, it is impossible to construct a task that purely measures knowledge, but does not require any mechanic aspects of information processing. The retrieval and application of knowledge might even be constrained more and more by the cognitive mechanics with increasing age. The finding of knowledge tasks showing negative age correlations in the BASE data (Lindenberger & Baltes, 1997), as opposed to the positive correlations reported by Salthouse (2001; Salthouse & Czaja, 2000), as well as recent longitudinal analyses—showing a leading declining effect of speed on the decline in knowledge (Ghisletta & Lindenberger, 2001)—support such a view.

Based on these possible explanations for the empirically observed correlations between mechanic and pragmatic abilities, the inclusion of a general factor in the presented models could be seen as an oversimplification of the complexity of these relations. The true interrelations among the different performance tasks cannot be modeled without some knowledge about the underlying processes, the influence of motivational factors, and the dynamic developmental interactions between the different abilities. Therefore, the general factor has to be interpreted as a parsimonious description of a much more complex reality. As such a simplified description, it can nevertheless be very useful in summarizing the relations of the cognitive domain to other domains of psychological and gerontological research. As the results of this thesis show, however, it is necessary to contrast the general factor with NF models that more comprehensively include specific sources of variance. Even though the general factor could account for a large portion of the shared variance among the cognitive tasks, it could not capture the differential age gradients of the mechanic and pragmatic abilities—as indicated by the significant positive age relations of the specific knowledge and fluency factors.

3.5 Antecedents, Correlates, and Consequences of the Cognitive Factors

The major strength of the NF model lies in its capacity to simultaneously relate general and specific factors of a multivariate structure of cognitive tasks to external criterion variables. While this model has been introduced to address the question of general versus specific effects of cognitive aging, it also allows examining the relative importance of general and specific factors in relating individual differences in cognitive abilities to other criterion variables. For the presented analyses, it was decided to treat external variables as correlates, not making claims about the causal relationships among cognitive abilities and the other theoretical constructs. The models in which external variables were used as dependent variables and predicted by the general and specific cognitive factors also should not be interpreted in a causal sense. These analyses were rather conducted to estimate the importance that specific factors have when individual differences in performance on cognitive tests are related to indicators of real life cognitive functioning. Using these variables as a dependent variable allowed the calculation of the summary measure of variance explained by the nested factors.

As an alternative to the presented models, one could also use age-partialled models by introducing age as a cause of the nested factors and the criterion variables into the models. This was only done for several control analyses (see Appendices G and H), because the goal of these analyses was to relate a comprehensive representation of individual differences in cognitive abilities to other variables. Using an age-partialled model would have removed potentially interesting variance here.

3.5.1 Education and Openness to Experience

Of special interest were the relations between education, openness, and cognitive abilities. For these variables, a complex developmental interplay of directional and reciprocal relations could be expected. On the one hand, higher cognitive abilities may lead to more intensive education and higher occupational prestige; on the other hand, schooling and occupations that are cognitively challenging might increase fluid and crystallized abilities as well. The investment theory of intelligence development further states that crystallized abilities accumulate by a process of *Gf* being invested into elaborating and memorizing complex facts (Cattell, 1971). This process, as well as the investment into education in general, in turn is moderated by motivation and interest that are partly captured by personality constructs, such as TIE and openness to ideas (Ackerman, 1996).

In cross-sectional data, these complex reciprocal developmental relations are confounded in the observed correlations. This is a general limitation of the analyses presented here, which were all exclusively based on cross-sectional data. However, the current findings that education was significantly related to the specific factors of reasoning (*Gf*) and knowledge (*Gc*), and the openness to ideas item was related to the specific knowledge factor, support the general theoretical notion of education promoting reasoning ability as well as the accumulation of knowledge—with intellectual interest being a moderator of these effects. General factor accounts could not adequately represent these relations of education and the intellectual curiosity item to the cognitive tasks.

It is of special interest that it was possible to demonstrate these relations in a sample of old and very old subjects, where the factor space of cognitive abilities was already very much dedifferentiated, and where a large part of the assumed developmental interactions probably took place way back in the individuals' past. This underscores the importance of engaging in concepts of cumulative developmental influences between environment and individual cognitive development (e.g., S.-C. Li, 2003).

3.5.2 Everyday Cognitive Competency

A second line of interest for external criterion variables was trying to predict everyday cognitive activities. Some evidence for such predictive validity was already contained in the NF measurement model. Of the 14 tasks in the BASE cognitive battery, three measured cognitive performance with contents of real life ecological validity. Those were the reasoning task *Practical problems*, the memory task *Activity recall*, and the *Practical knowledge* task. All three tasks had significant loadings on their specific factor. For Practical problems, this implied that about 14% of the reliable variance was explained by the specific factor. This task, which was adopted from the ETS Basic Skills Test (Educational Testing Service, 1977), has exhibited strong relations to measures of *Gf* in other studies (Willis & Schaie, 1986). Therefore, in BASE it was decided to use this task as an indicator variable for reasoning. Because it measures reasoning with items of real life problems, such as understanding instructions for medication or bus schedules, it emphasizes the importance of practical everyday competence captured by the specific reasoning factor.

The prediction of everyday cognitive competency was further pursued with the activities coded in the *Yesterday Interview* (M. M. Baltes et al., 1993). The strongest relations to the cognitive tasks were found for the *Writing* activity. These relations were exclusively mediated by the specific factors. About one fourth of the variance in the duration of writing activities could be accounted for by the specific factors of speed, fluency, and reasoning. In contrast, the general factor was strongly related to the basic competency index. While this finding clearly demonstrates the limitations of a general factor account, an unambiguous interpretation of the relations to these specific factors is prevented by two problems. First, as argued in an earlier section, it is not clear what cognitive resources the specific factors exactly measure. Second, it would be necessary to more precisely specify in what kind of writing activities the individual subjects actually did engage. Different kinds of writing activities, such as writing personal letters, diaries or working on scientific manuscripts, that were all coded into the same category, might require different specific cognitive abilities in addition to general cognitive functioning.

3.5.3 Broad Versus Narrow Criterion Variables

A general pattern that emerged from the results of the analyses on predicting external criterion variables is that the general factor of the cognitive battery showed its strongest relations to aggregated measures, while the specific factors could add portions of explained variance if broad measures were disaggregated to the level of specific behaviors. The relation of the specific reasoning factor to education disappeared when education was combined with the other SES measures. Summing up the items of the openness scale averaged out interesting correlation patterns between its single items and the specific cognitive factors. Finally, the combined index of expanded competency activities (ExCo) only showed a correlation with the general factor, covering up specific factor relations to its constituent items, such as writing activities. The pattern seems obvious: aggregated criterion variables can be best explained by general predictors, while specific criteria can only show significant correlations with predictor variables at the same level of generality (Wittmann, 1988; Wittmann & Süß, 1999). If aggregated variables are not strictly unidimensional, then important sources of variance might have been averaged out by aggregation. When examining relations to other theoretical constructs, the higher reliability of a sum score may not pay off when items or variables that do not strongly relate to the criterion are included. For the specific sources of variance that are contained in the NEO facets—and averaged in the NEO scales—Paunonen and Ashton (2001), for instance, have shown incremental predictive validity for a number of criterion variables. Such analyses on the disaggregated level of single items—or specific variables—however, should be based on theoretical rationales and have to employ analytical strategies that prevent capitalizing on chance effects if analyses are conducted with large numbers of variables.

The presented analyses on external criterion variables were rather exploratory, searching the large collection of variables provided by BASE for constructs that could be expected to show correlations with the cognitive measures. Therefore, the presented results should be taken more as an existence proof of specific factor relations than as tests of explicit hypotheses. It might be possible, however, to design new studies with specific criterion measures of everyday cognitive functioning that can be expected to show unique relations to the different specific factors—similar to the everyday cognition measures of inductive reasoning, working memory, declarative memory, and knowledge used by Allaire and Marsiske (1999).

3.5.4 Nested Factor Models of Cognitive and Sensorimotor Variables

Previous approaches to test the common cause hypothesis with mediation models based on cross-sectional data have used models with a common cause factor and then added specific paths from age to its indicator variables (e.g., Christensen et al., 2001). In the empirical section, it has been demonstrated that NF models are flexible enough to represent the hierarchical structure implied by the common cause hypothesis by including a common cause factor with loadings of all cognitive and sensorimotor variables. Furthermore, a general factor of the cognitive mechanics and specific factors of reasoning, memory, perceptual speed, and sensorimotor functioning were included. The common cause factor, therefore, captured the variance that was common to all variables, without having to explain all of the variance that was common to the mechanic abilities. This allowed for a simultaneous estimation of the amount of age variance that could be explained by a common cause factor, together with potential age-relations of the general mechanics and the specific factors. Results showed that the common cause factor captured practically all age-associated variance of the cognitive mechanics and a large portion of the age-associated variance of the sensorimotor variables. However, there was an additional strong and significant age correlation of the specific sensorimotor factor.

Because the parameters of the measurement model were not fixed in these analyses and all age correlations were estimated simultaneously, in principle, the age-associated variance of the cognitive mechanics could as well have been explained by the general cognitive factor. Still, the internal relations among the variables defined a factor-loading pattern with a strong common cause factor and a very weak factor of general mechanics. While obviously there was some part of age-associated variance in the sensorimotor variables that could not be explained by a common cause factor, the finding that this factor—which mediated all age-related variance of the cognitive mechanics—had high loadings of the sensorimotor variables supports the common cause hypothesis of a strong coupling of cognitive mechanics and sensorimotor functioning in old age. This pattern of age relations of the factors can be explained by (a) decline processes in central information processing that are domain general and, therefore, affect cognitive performance as well as parts of sensory information processing, together with (b) independent processes that specifically affect sensory and psychomotor performance.

3.6 Technical Issues and Monte Carlo Study

Based on the results of the Monte Carlo study, several conclusions and recommendations for designing multivariate correlational studies that aim at disentangling general and specific effects could be drawn. Using the NF model, possible estimation problems such as nonconvergence or improper solutions are closely related to the more general issue of parameter interdependence and sensitivity. As shown in the Monte Carlo study, these problems could be reduced if the ratio of general and specific variance is not homogenous across the tasks of the ability constructs.

3.6.1 Estimation Problems

Trying to estimate parameters of a NF model with SEM programs can lead to estimation problems like nonconvergence of the optimization process, Heywood cases (negative error variances), and improper solutions. These problems are well known from the mathematically very similar, or even identical, multitrait-multimethod models (Marsh, 1989). Even though not encountered in the presented analyses, in the case with smaller sample sizes estimation problems might seriously complicate data analysis and interpretation of results. The Monte Carlo simulation showed that the general recommendations of using at least three indicators per latent construct and to have sample sizes not smaller than 150 cases (e.g., Anderson & Gerbing, 1984) are also valid for the application of the NF model. To reduce the probability of Heywood cases, there was a clear advantage of the condition with a sample size of 250 over a sample size of 125, and of using four instead of three indicators per factor. The number of improper solutions, which were a result of the more general problem of parameter interdependencies among the general and specific effect estimates, however, was more strongly influenced by the disproportionality of general and specific variance in the indicator variables than by sample size and number of indicator variables.

Before discussing this effect, however, a number of actions that can be taken to try to prevent or circumvent the estimation problems should be mentioned. First, it is of special importance to have good starting values. While SEM programs differ in how they compute starting values and, therefore, it sometimes helps to run the same model with different software, one can also try coming up with good starting values manually. It sometimes can also be beneficial to try out different parameterizations of the model, such as choosing between fixing a latent variance or a factor loading to one to identify the scale of a factor. Second, it might help to try out different estimation techniques, if the SEM software used provides a choice of them. Using SAS PROC CALIS (SAS Institute, 1989a) with its elaborated methods of determining starting values and its choice of different iterative optimization techniques, in most presented cases the NF model parameters could be estimated without convergence problems.

3.6.2 Disproportionality of General and Specific Variance in the Indicator Variables

In the theoretical part of this thesis, it has been explained how the NF model is capable of capturing empirical heterogeneity of the ratio of general and specific variance across the indicator variables of each first-order construct. This was not possible with the hierarchical model, which puts a proportionality constraint on this ratio. The influence of such disproportionality on the parameter estimation dynamics was examined in the Monte Carlo simulation by manipulating the empirical disproportionality as an experimental factor in the study design. Results showed that the disproportionality had a strong impact on parameter sensitivity and interdependency of the general and specific effect estimates. This effect was manifested in smaller standard errors and a lower base rate of improper solutions with increasing disproportionality. This implied that disproportionality is beneficial for disentangling general and specific effects. It is not clear, however, how indicator variables should be selected or constructed to increase the empirical disproportionality in tasks that, at the same time, should represent theoretical constructs.

However, some general remarks of how this could be approached can be made. Using two parallel versions of the same task as the only indicators of a latent factor will probably not work well, because in such a case the ratio of general and specific variance will be almost equal in both task versions. The empirical situation in the BASE cognitive battery, with a heterogeneous sampling of tasks representing the theoretical constructs, did allow for a satisfactory separation of general and specific factors and their age relations. To further improve the disentangling of general and specific factors, a task construction that builds on a theory-guided specification of task components is probably essential. Such a theory-based task construction would require to hold some general task components constant across a set of tasks and to introduce specific requirements of increasing amount for subsets of the tasks. For example, to disentangle the processing component from the short-term memory component in working memory tasks, one might use several tasks with the same short-term memory requirement and an increasing processing demand across some of the tasks, or vice versa. Applying a NF model with all tasks loading on a general factor, and the tasks with the additional demand loading on a specific factor could then allow separating the basic from the specific age relations.

The NF model, therefore, could build a methodological means to link individual difference studies with experimental task construction.

3.7 Future Directions

In this thesis it has been shown by means simulation examples that the NF model is capable of disentangling general and specific effects of aging in an unbiased way and has elaborated that the reason for this lies in its flexibility to account for varying ratios of general to specific variance in the indicator variables. In the empirical part, it has been demonstrated that the NF model, indeed, allowed for a simultaneous estimation of general and specific effects and further examples of other aspects of the NF model's flexibility to address a variety of research questions were given. First, it allows addressing directly the issue of factor structure dedifferentiation by comparing the communalities of the general versus specific factors. Second, the NF model can serve not only to disentangle general and specific relations to age, but to any other external criterion variable as well. Third, it is capable to represent several strata of generality, as the combination of a general plus specific factor model for the cognitive variables with a common cause factor including sensorimotor variables has shown.

This flexibility of the NF model to account for all kinds of hierarchical model structures could be used in future research on general and specific effects of cognitive aging to include latent constructs of the information-processing tradition and to examine relations of the general and specific factors to general and specific external criterion variables that are chosen in a way that parallels the structure of the cognitive abilities. Furthermore, the NF model could be used in other research fields within cognitive developmental psychology that also work on issues of general versus specific effects, such as the current debates of whether cognitive development in childhood and the effects of genetic dispositions on cognitive abilities are *molar* or *modular* (e.g., Alarcón, Plomin, Fulker, Corley, & DeFries, 1999; Pedersen, Plomin, & McClearn, 1994; Petrill, 1997).

3.8 Conclusions

The use of structural models to represent the multivariate picture of cognitive aging can produce biased results if these models do not adequately represent the internal structure of the cognitive variables or if stepwise procedures are used that prioritize general over specific effects. Due to the use of such biasing methods, the importance of specific factors in cognitive aging probably has been underestimated in a number of existing studies. The NF model has been introduced as an alternative representation. This model class allows the examination of the general and specific relations of individual differences in multiple measures of cognitive functioning with age and other external criterion variables in an unbiased way.

Results from the analyses of BASE data showed that a general factor alone could not adequately represent the structure, age relations, or relations to external criterion variables. Rather, specific group factors contributed significantly and substantially to the observed variance of cognitive tasks and did explain an important portion of age- and criterion-related variance in the dedifferentiated factor space characterizing the old and oldest-old. It is therefore necessary and beneficial to consider individual differences in cognitive functioning as multidimensional, multidirectionally related to age, and multifunctional in their predictive validity for outcome measures even in old and very old age.