Original Article

Correspondence Between the General Ability to Discriminate Sensory Stimuli and General Intelligence

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Abstract. For more than a century the veracity of Spearman's postulate that there is a nearly perfect correspondence between general intelligence and general sensory discrimination has remained unresolved. Most studies have found significant albeit small correlations. However, this can be used neither to confirm nor dismiss Spearman's postulate, a major weakness of previous research being that only single discrimination capacities were considered rather than general discrimination. The present study examines Spearman's hypothesis with a sample of 1,330 5- to 10-year-old children, using structural equation modeling. The results support Spearman's hypothesis with a strong correlation (r = .78). Results are discussed in terms of the validity of the general sensory discrimination factor. In addition, age-group-specific analyses explored the age differentiation hypothesis.

Keywords: general intelligence, general sensory discrimination, visual discrimination, haptic discrimination, age differentiation hypothesis

Introduction

Can intelligence be inferred from the observation of how individuals order lines according to their lengths or blocks according to their weights? According to Spearman, the answer is yes. Spearman (1904) postulated in his seminal article on objective determination and measurement of general intelligence a near-absolute correlation between the ability to discriminate sensory stimuli and general intelligence. This assumption was the subject of controversy at the beginning of the 20th century and left to rest until recent years (Deary, 1994b; Deary, Bell, Bell, Campbell, & Fazal, 2004).

Spearman's hypothesis can be traced back to Galton (1883), who stated that individuals with higher cognitive abilities are capable of more accurate sensory discrimination than individuals with lower cognitive abilities. Galton himself was inspired by Locke (e.g., 1690), who assumed that knowledge, which forms the foundation for complex cognitive functioning, derives from sensations. Spearman (1904) examined and elaborated on Galton's idea. In his day there was great controversy over whether basic cognitive processes such as sensory discrimination are related to higher cognitive abilities (Deary, 1994b; Deary et al., 2004).

Researchers nowadays largely agree that there are significant correlations between sensory discrimination capacities and intelligence, but that these correlations are moderate (Acton & Schroeder, 2001; Danthiir, Roberts, Pallier, & Stankov, 2000; Deary, 1994a; Deary et al., 2004; Deary, Caryl, Egan, & Wight, 1989; Ghisletta & Lindenberger, 2005; Helmbold, Troche, & Rammsayer, 2006; Irwin, 1984; Li, Jordanova, & Lindenberger, 1998; Lindenberger & Baltes, 1994; Lynn, Wilson, & Gault, 1989; Raz, Willerman, Ingmundson, & Hanlon, 1983; Raz, Willerman, & Yama, 1987; Roberts, Stankov, Pallier, & Dolph, 1997). These findings, as Deary and colleagues (2004) stated, neither confirm nor contradict Spearman's postulate of a near-absolute correlation between sensory discrimination and intelligence. Spearman (1904) did not assume that single sensory discrimination capacities strongly correlate with intelligence, but rather that "General Discrimination," as Spearman provisorily called his constructs, nearly perfectly correlates with "General Intelligence" (p. 284). In support of his hypotheses Spearman found high correlations in his experiments between the general ability to differentiate sensory stimuli and intelligence (r = .96, r = 1.04; coefficients greater than 1 are possible with Spearman's formulas). In conclusion, Spearman stated in his seminal article, "Thus we arrive at the remarkable result that the common and essential element in the Intelligences wholly coincides with the common and essential element in the Sensory Functions" (p. 269, italics omitted). Note that the associations between the single sensory discrimination test performances and intelligence in Spearman's examinations were,

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like those obtained in current studies (e.g., Acton & Schroeder, 2001), rather moderate (r = .34 to .51; corrected r = .43 to .78).

Spearman's hypothesis was first addressed directly by Deary et al. (2004), who described two studies in which they examined the relationship between general sensory discrimination and cognitive performances by means of structural equation modeling. The results of the first study showed a strong correlation between general discrimination and intelligence with r = .92. The single lower-level correlations turned out, as expected, to be generally significant albeit moderate, with significant values varying from r = .28 to r = .45. The results of the second study, with r = .68, pointed to a lower but still high correlation of the latent constructs. The single correlations were again low with significant correlations of r = .11 to r = .32.

This study examines Spearman's hypothesis of near-perfect correlation for the first time with children aged 5 to 10 years, the ages of subjects in Spearman's (1904) original work. Furthermore, we test whether the relationship between general discrimination and general intelligence decreases over the age group. This assumption is based on Deary et al.'s (2004) noteworthy finding that the correlations between sensory discrimination and general intelligence were different in their first (r = .92) and second (r = .68) studies. An interesting explanation for the difference in the correlations was given by the subjects' ages (Study 1: M_{age} = 12.2 years, SD_{age} = 3.2 months; Study 2: M_{age} = 27.4 years, SD_{age} = 10.3 years). Deary and colleagues assumed, as did Spearman (1926, 1927), that the general intelligence (g) factor might lose strength in the course of cognitive development from infancy to adulthood. As a result, cognitive test performances should decreasingly intercorrelate as a person approaches adulthood. Spearman dubbed this effect the *law of diminishing returns*. He also assumed that the correspondence between cognitive abilities decreases with increasing cognitive ability level. Later Garrett (1946) coined the term *differentiation hypothesis,* or more specifically regarding the age effect, the *age differentiation hypothesis.*

Method

Participants

The sample comprised 1,330 children from 5 years, 0 months to 10 years, 11 months (M = 8 years 0 months, SD = 1 year 8 months). Of the 668 girls and 662 boys, 747 were from Switzerland (49.7% girls), 344 from Germany (51.7% girls), and 239 from Austria (49.8% girls). There were no important differences in the children's test performances between the countries ($\overline{\eta}^2$ = .008; $\eta^2 < .01$ is seen as small; Cohen, 1988). For this study the children were sorted by age into three groups, namely, 5 years, 0 months to 6 years, 11 months (n = 413; 50.4% girls), 7 years, 0 months to 8 years, 11 months (n = 493; 50.5% girls), and 9 years, 0 months to 10 years, 11 months (n = 424; 49.8% girls), respectively. The age classes did not differ significantly (p > .05) on variables that might have an influence on the results, such as children's intelligence level and parents' socioeconomic status. All children participated voluntarily and with their parents' consent. They were recruited from daycares and schools. The recruitment took place as part of the standardization of the Intelligence and Development Scales in the German-speaking area (IDS; Grob, Meyer, & Hagmann-von Arx, 2009). Testing was conducted at various school psychology centers and at the children's own schools or daycares. At the end of the standardization study, the parents received a written report on their children's stage of development. If there were questions or concerns regarding the test results, parents were invited to consult with experienced school psychologists for free.

Procedure and Measures

Cognitive and sensory discrimination capacities were recorded using the IDS. The test consists of 19 subscales measuring general intelligence as well as the stage of development of psychomotricity, social-emotional competence, mathematics, language, and the achievement motivation of children aged 5 years, 0 months to 10 years, 11 months. The IDS have their roots in a complete reconception of the Kramer Intelligence Test (Kramer, 1972; for a history of test development see Hagmann-von Arx, Meyer, & Grob, 2008b), which in turn directly refers to the Binet-Simon Test (Binet & Simon, 1905). The IDS contain classic tasks of intelligence assessment (Reuner & Pietz, 2006). The test was administered to subjects individually.

Cognitive Ability Tests

The cognitive ability tests of the IDS were Memory Auditory (MA; retelling a previously heard story), Memory Phonological (MP; repeating previously heard sequences of letters and numbers), Memory Visual-Spatial (MV; identifying previously seen geometric figures in an assortment of figures disregarding the color), Reasoning Conceptual (RC; identifying the superior category of imaginary concepts), Reasoning Figural (RF; constructing imaginary figures with blocks), and Attention Selective (AS; finding and marking drawings of drakes with specific attributes in lines of different drakes within a stated time). The internal consistency (Cronbach's α) of the cognitive IDS subscales ranged from α = .68 to α = .96 (Table 1) with an overall reliability of α = .92. The criterion validity with the Hamburg Wechsler Intelligence Scale for Children IV (HAWIK-IV; Petermann & Petermann, 2008), the German adaption of the Wechsler Intelligence Scale for Children IV (WISC-IV; Wechsler, 2003), proved to be r = .70 (for more details on the validity of the IDS see Grob et al., 2009; Hagmann-von Arx, Meyer, & Grob, 2008a,c; Meyer, Hagmann-von Arx, & Grob, 2009). The IDS test battery is designed to measure cognitive abilities on a broad level. It is therefore well suited to capturing general intelligence.

Sensory Discrimination Tests

The sensory discrimination tests of the IDS include a visual and a haptic discrimination subscale. The children's task in the Sensory Discrimination Visual test (DV) is to arrange cards, which are each printed with a line of varying length, in a row, according to the lengths of the lines. There are seven sets, each consisting of seven cards (except the elementary set, which has four cards). The differences in the lengths decrease across the sets from 10 mm to 0.25 mm. The line lengths are between 10 and 40 mm with a thickness of 1 mm. The internal consistency (Cronbach's α) of this subscale was α = .77. In classic research (Abelson, 1911; Stevenson, 1918; Thorndike, 1909; Thorndike, Wil-

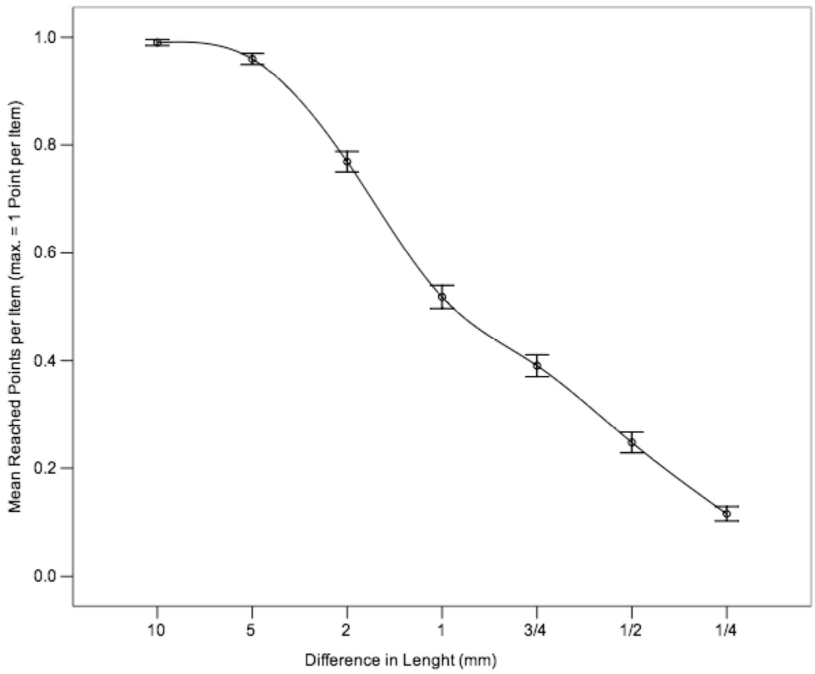

Figure 1. Mean number of points reached on the visual discrimination test at different levels of stimulus difference (maximum score per item converted to 1 point; originally, in the elementary set a maximum of 4 points and in the test sets a maximum of 7 points per set could be reached).

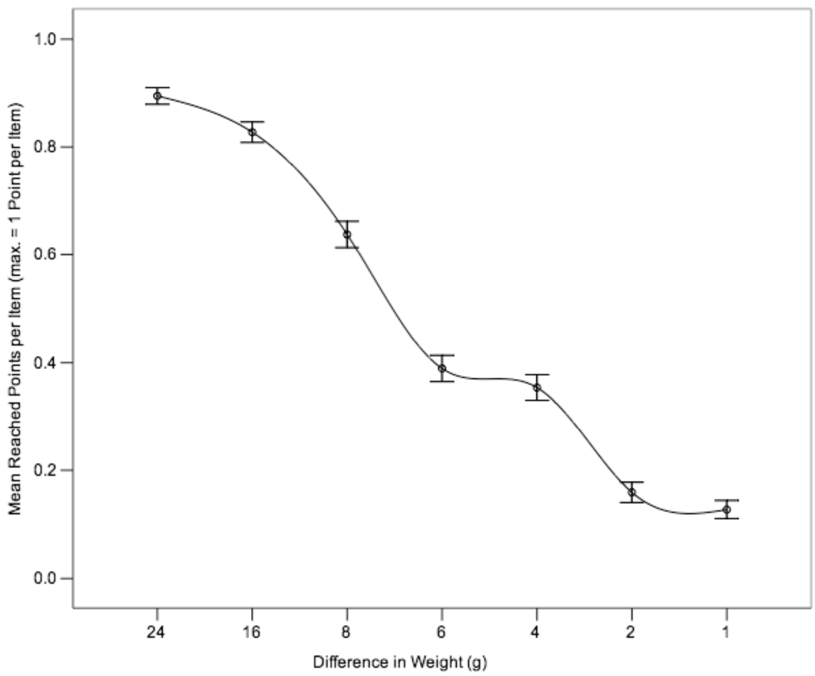

Figure 2. Mean number of points reached on the haptic discrimination test at different levels of stimulus difference.

frid, & Deam, 1909) and developmental tests (Binet, 1911; Binet & Simon, 1905; Norden, 1953; Terman & Merrill, 1960) as well as is in current studies (Deary et al., 1989; McCrory & Cooper, 2007) this kind of task was used as a measure of visual discrimination.

For the Sensory Discrimination Haptic test (DH) the children are asked to arrange small seemingly identical blocks in a row according to their weights. There are seven sets, each consisting of three bars. The differences in the weights range from 24 g to 1 g, following Deary et al.'s (2004) weights test. The internal consistency (Cronbach's α) of this subscale was $\alpha = .60$. Weight discrimination tasks were often used in classic research (Abelson, 1911; Carey, 1914–1915; Spearman, 1904; Thorndike; 1909; Thorndike et al., 1909). Nowadays, only a few report analyses of haptic discrimination.

In both sensory discrimination tests, all children initially receive the simplest set with the largest existent length or weight difference between the materials. Accordingly, the difficulty of the sets increases steadily. The materials are presented at random and scattered. An underlay (a table mat that serves as a surface for working on the task) for both discrimination tests provides both assistance and a standard presentation format. In the visual discrimination test, the underlay displays rectangles printed in a row on which the children have to lay the accordant cards. In the haptic discrimination test, the underlay displays circles printed in a row on which the children have to put the accordant blocks. For more details on the IDS subscales see Grob et al. (2009).

Statistical analyses revealed that the visual and haptic discrimination subscales showed a satisfactory range, with items on the simplest level that could be solved by nearly every child to items on the most difficult level that could be solved by almost no child. The difficulty index increased steadily over the test items (Figure 1 & Figure 2).

Results

Descriptive Statistics and Correlations

Means, standard deviations, and correlations of the cognitive and sensory discrimination subscales of the whole sample as well as the age groups are given in Table 1. The means of the raw test scores show clear age trends, pointing to the test design's construct validity. All calculations were conducted with SPSS 16.0 (SPSS Inc., Chicago, IL, USA). The Pearson method was applied and the age-standardized test scores were used for the correlations. The intelligence as well as the sensory discrimination subscales correlated among themselves overall significantly, with significant intercorrelation ranges of $r_{\text{age group 5 to 10 years}} = .25$ to $.07$ ($M = .17$, $SD = .06$;[1]; the effect sizes of the correlations range from $d = .52$ to $.14$[2]), $r_{\text{age group 5 to 6 years}} = .35$ to $.12$ ($M = .19$, $SD = .10$; $d = .74$ to $.24$), $r_{\text{age group 7 to 8 years}} = .26$ to $.12$ ($M = .18$, $SD = .06$; $d = .54$ to $.24$), and $r_{\text{age group 9 to 10 years}} = .24$ to $.09$ ($M = .15$, $SD = .05$; $d = .49$ to $.18$) for the cognitive subscales, and intercorrelations of $r_{\text{age group 5 to 10 years}} = .12$ ($d = .24$), $r_{\text{age group 5 to 6 years}} = .15$ ($d = .30$), $r_{\text{age group 7 to 8 years}} = .13$ ($d = .26$), and $r_{\text{age group 9 to 10 years}} = .07$ ($d = .14$) for the sensory discrimination subscales. Moreover, significant correlations between intelligence and sensory discrimination tests were found, with ranges of $r_{\text{age group 5 to 10 years}} = .25$ to $.07$ ($M = .13$, $SD = .08$; $d = .14$ to $.52$), $r_{\text{age group 5 to 6 years}} = .30$ to $.10$ ($M = .16$, $SD = .11$; $d = .63$ to $.20$), $r_{\text{age group 7 to 8 years}} = .21$ to $.08$ ($M = .11$, $SD = .07$; $d = .43$ to $.16$), and $r_{\text{age group 9 to 10 years}} = .27$ to $.09$ ($M = .12$, $SD = .09$; $d = .56$ to $.18$). The correlations between the visual discrimination subscale and the cognitive subscales appeared larger than the correlations between the haptic discrimination subscale and the cognitive subscales. The latter correlations were generally weak or approached zero. The haptic discrimination capacity correlated in general stronger with the visual discrimination capacity than with the other cognitive aptitudes. In the sample as a whole as well as in the three age groups all correlations were significant at the .001 α level except correlations of the haptic discrimination and selective attention subscales. The correlations (for the total sample without brackets, for the age groups within brackets) from $r = .06$ to $r = .05$ (from .11 to .08) were significant at the .05 α level, correlations of $r = .04$ (from .07 to .06) were marginally significant, and correlations below $r = .04$ (.06) were not significant.

Correspondence Between General Discrimination and General Intelligence

To examine Spearman's hypothesis that general discrimination and general intelligence nearly perfectly correlate, a confirmatory factor analysis by means of structural equation modeling was conducted. For this purpose the age-standardized total scores of the visual discrimination (DV) test, the haptic discrimination (DH) test, and the intelligence tests (MA, MP, MV, RC, RF) were obtained. AMOS 6.0 (Arbuckle, 2005) was used for the calculations, and the maximum likelihood method was applied. In addition, the model was tested using the robust unweighted least squares method. Because the results were virtually identical with those from the maximum likelihood analyses (the factor scores of the two methods of calculation correlated at $r > .99$), only the results from the maximum likelihood analyses are reported.

Two structural models were constructed: Model 1 is presented in Figure 3. Free parameters were the size of the

1 *M* and *SD* in this section refer to all correlations independent of their significance
2 According to Cohen (1988) $d = .20$ corresponds to a small effect, $d = .50$ a moderate effect, and $d = .80$ a large effect.

Table 1. Intercorrelations between cognitive and sensory discrimination subscales separated by age group as well as descriptive statistics and Cronbach's α values of the subscales

Subscale		Age (years)	MA	MP	MV	RC	RF	AS	DV	DH
Memory Auditory	(MA)	5–10	–	.25	.22	.24	.16	.17	.20	.09
		5–6	–	.34	.21	.32	.15	.20	.30	.10
		7–8	–	.26	.24	.21	.20	.20	.16	.08
		9–10	–	.16	.21	.20	.13	.11	.15	.10
Memory Phonological	(MP)	5–10		–	.17	.17	.15	.15	.20	.04
		5–6		–	.17	.24	.14	.18	.26	–.01
		7–8		–	.15	.13	.18	.13	.13	.06
		9–10		–	.19	.13	.14	.16	.23	.06
Memory Visual-Spatial	(MV)	5–10			–	.24	.20	.11	.18	.11
		5–6			–	.35	.20	.03	.24	.21
		7–8			–	.20	.24	.17	.14	.04
		9–10			–	.20	.17	.12	.19	.10
Reasoning Conceptual	(RC)	5–10				–	.21	.07	.18	.07
		5–6				–	.20	.12	.21	.14
		7–8				–	.19	.02	.18	.03
		9–10				–	.24	.09	.16	.07
Reasoning Figural	(RF)	5–10					–	.07	.25	.04
		5–6					–	.04	.29	.07
		7–8					–	.12	.21	.10
		9–10					–	.04	.27	–.06
Attention Selective	(AS)	5–10						–	.14	.00
		5–6						–	.19	–.04
		7–8						–	.15	.00
		9–10						–	.09	.05
Discrimination Visual	(DV)	5–10							–	.12
		5–6							–	.15
		7–8							–	.13
		9–10							–	.07
M		5–10	28.7	6.6	5.7	6.3	5.6	120.5	24.0	3.4
		5–6	21.9	5.4	4.5	4.7	4.5	85.0	19.9	2.8
		7–8	30.1	6.9	5.8	6.7	5.9	123.7	25.1	3.4
		9–10	35.2	7.7	6.9	7.7	6.7	152.2	28.5	3.8
SD		5–10	8.9	2.0	2.0	2.4	1.8	44.2	7.9	1.5
		5–6	7.7	1.7	1.7	2.0	1.6	31.7	7.4	1.5
		7–8	6.5	1.7	1.6	2.0	1.5	30.5	6.6	1.5
		9–10	5.3	1.8	1.5	2.0	1.4	32.4	5.9	1.4
α (Cronbach's alpha)			.87	.73	.68	.75	.70	.96	.77	.60

Note. The correlations were calculated with the age-standardized test scores; for the means, standard deviations, and Cronbach's α values the row test scores were used. Sample size $N_{\text{age group 5 to 10 years}}$ ranged from 1330 to 1218; $n_{\text{age group 5 to 6 years}}$ from 413 to 361; $n_{\text{age group 7 to 8 years}}$ from 493 to 458; $n_{\text{age group 5 to 10 years}}$ from 424 to 390. All correlations (for the whole sample without brackets, for the age groups within brackets) greater than $r = .06$ (.11) are significant at $p < .001$; correlations from $r = .06$ to .05. (.11 to .08) are significant at $p < .05$, correlations of $r = .04$ (from .07 to .06) are marginal significant and correlations below $r = .04$ (.06) are not significant. DH = Discrimination Haptic

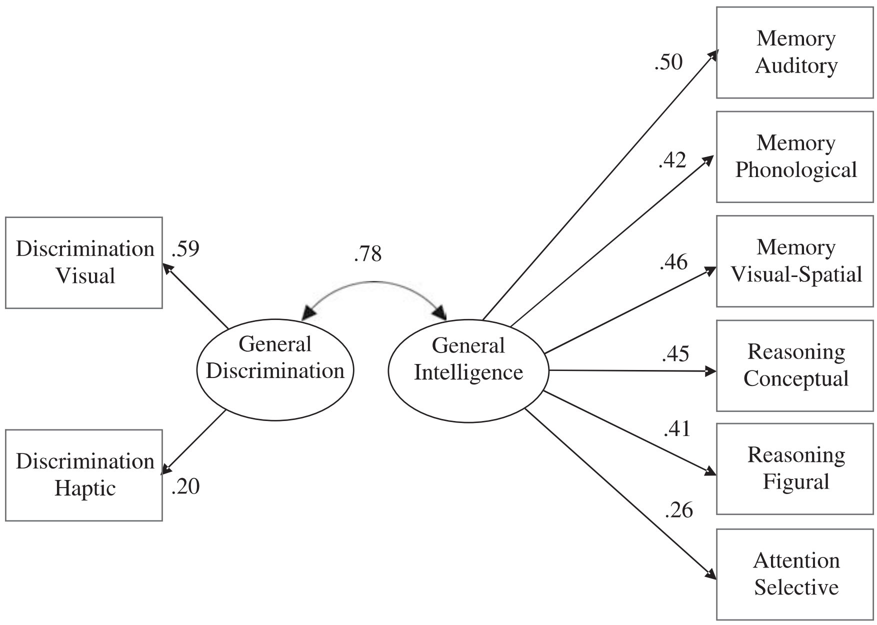

Figure 3. Structural equation model of the relationship between general discrimination and general intelligence. The calculations were conducted with the whole sample.

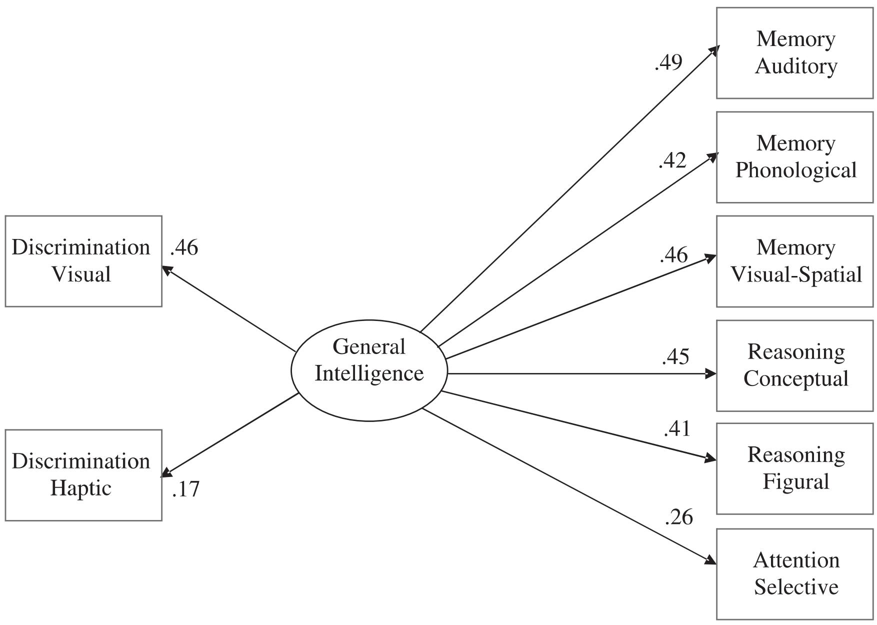

Figure 4. Structural equation model representing Spearman's hypothesis of an exact functional correspondence between sensory discrimination and intelligence. The calculations were conducted with the whole sample.

correspondence between the two latent variables as well as the factor loadings of the cognitive abilities and sensory discrimination tests with their corresponding factors. The second, more economical model was additionally designed with just a single factor capturing all the shared variance between the visual discrimination and psychometric intelligence scores (Figure 4). All correlations with the single general factor were free parameters.

Model 1 (Figure 3) fits the data well, as the following indices indicate: $\chi^2 = 47.16$ ($df = 19$, $p < .001$), CMIN/df = 2.48, goodness-of-fit index (GFI) = .99, comparative fit index (CFI) = .96, root mean square error of approximation (RMSEA) = .03 (90% confidence interval ranging from .02 to .05). All specified paths in the structural equation model were highly significant at $p < .001$. The two sensory discrimination tests in the model have adequately high loadings on the discrimination factor and the psychometric tests show adequately high loadings on the intelligence factor (factor loadings greater than .20 are seen as noticeable and factor loadings greater than .50 are seen as high; Stevens, 1996). The obtained correspondence between general discrimination and general intelligence was $r = .78$ ($p < .001$), $SE = .09$.

For Model 2 (Figure 4) the model indices were $\chi^2 = 49.96$ ($df = 20$, $p < .00$), CMIN/df = 2.50, GFI = .99, CFI = .96, RMSEA = .03 (90% confidence interval ranged from .02 to .05), which indicates a good model fit. All paths are significant at $p < .001$. The factor loadings of all subscales

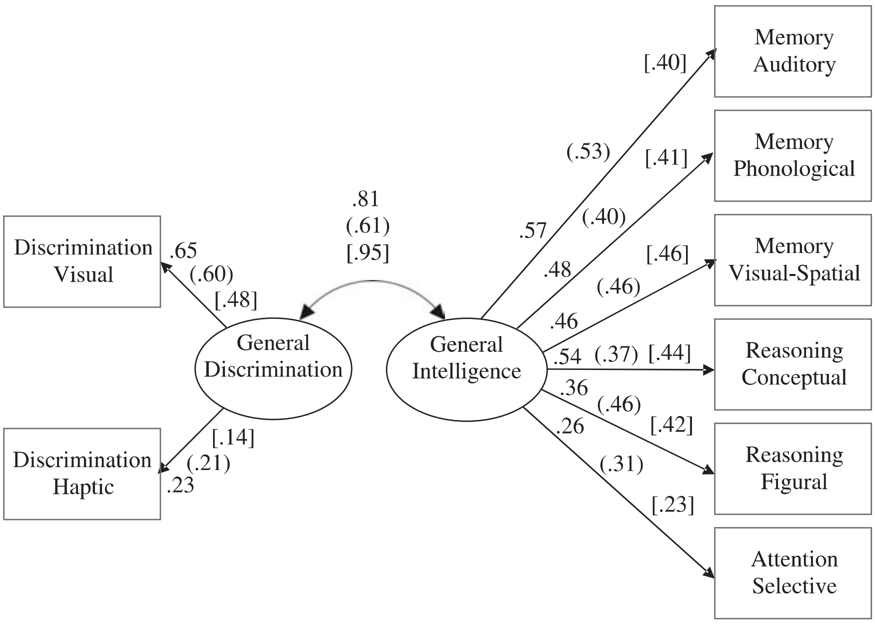

Figure 5. Structural equation model of the relationship between general discrimination and general intelligence. The calculations were performed in a multigroup analysis with the age groups 5 to 6, 7 to 8, and 9 to 10 years (coefficients for the 7- to 8-year-old children in round brackets, for 9- to 10-year-olds in square brackets).

have adequately high associations with the general intelligence factor (extracted from both sensory discrimination and intelligence tests). The fits for Models 1 and 2 do not differ significantly; χ^2 for model differences = 1.59 (df = 1). Model 2 may be preferred for reasons of economy. Compared with Model 1, it possesses an extra degree of freedom without significant reduction of goodness of fit.

Age Differentiation of the Correspondence Between General Discrimination and General Intelligence

To test whether the correlation strength between the general discrimination and general intelligence factors declines across the age groups according to the age differentiation hypothesis, the structural equation model was administered in a multigroup analysis to the three age groups. The ranges cover preschool, early elementary, and later elementary school years and correspond to the 2-year brackets chosen by Spearman (1927).

Before computing the structural equation model, we examined whether the factors compared were the same irrespective of the age group (McArdle, 1996). For this purpose we used two statistical methods: First, the measurement weights model (a model with fixed factor loadings across the age groups) was compared with the unconstrained model (Byrne, 2004). There was no significant change in χ^2 (p = .59) across the models. Second, the congruence coefficients were computed (Cattell, 1978). Coefficients above +.90 imply a high degree of factor similarity, and values above +.95 indicate the factors are virtually identical (Jensen, 1998). The congruence coefficients for the general intelligence factor (and for the sensory discrimination factor in brackets) when compared to the next age group were .981 (.999) and .986 (.999), and when compared to the youngest age group .987 (.998). The two analyses indicate nearly identical general factors across the age groups.

The structural equation model (Figure 5) fits the data well, χ^2 = 99.73 (df = 57, p < .001), CMIN/df = 1.75, GFI = .98, CFI = .94, RMSEA = .02 (90% confidence interval ranging from .02 to .03). All paths in the model were significant at p < .001 except for the path between DH and general sensory discrimination, which was significant at $p_{\text{age group 5 to 6 years}} < .01$ and $p_{\text{age group 9 to 10 years}} < .05$. The correspondence between the general discrimination and general intelligence factors fluctuated across the three age classes from r = .81 (SE = .16) to r = 61. (SE = .13) to r = .95 (SE = .19).

Discussion

Evidence for the Correspondence Between General Intelligence and General Sensory Discrimination

Consistent with Spearman's (1904) theory, we found a high correlation of r = .78 between general sensory discrimination and general intelligence among children between 5 and 10 years old. This result supports Spearman's postulate that an essential element in general intelligence coincides with an essential element in the sensory functions. The outcome also aligns with the findings of Deary et al.'s (2004) studies, in which high correlations of r = .92 and r = .68 were found. Additional support for Spearman's thesis comes from the finding that a single-factor structural equation model fit the data just as accurately as a two-factor model. Yet we faced some challenges building the general sensory discrimination factor due to the rather moderate factor loading of the haptic discrimination subscale. The results have to be seen in this light.

Alteration of the Correspondence Between General Intelligence and General Sensory Discrimination with Increasing Age

We did not find a continual decline in the correspondence between general sensory discrimination and general intelligence. Following Spearman's age differentiation hypothesis, we predicted declining correlations between general discrimination and general intelligence. This was not supported by our results. The sensory discrimination-intelligence correlations in fact decreased from the youngest to the middle age group, but increased from the middle to the oldest age group ($r_{\text{age group 5 to 6 years}} = .81$, $r_{\text{age group 7 to 8 years}} = .61$, $r_{\text{age group 9 to 10 years}} = .95$).

At first glance these results stand in contrast to the previously reported age differentiation effects. However, it is important to note that the effects found in earlier studies (e.g., Asch, 1936; Balinsky, 1941; Burt, 1954; Clark, 1944; Filella, 1960; Garrett, 1946; Garrett, Bryan, & Perl, 1935; Lienert & Crott, 1964; McHugh & Owens, 1954) constitute an overall cognitive developmental trend. Here we focused on the change in the relationship between one kind of cognitive ability – sensory discrimination – and general intelligence[3].

An interesting explanation for the synclinical pattern might be the cognitive reorganization that likely takes place at the transition from preschool to school age. Theories that support this notion are Piaget's stage theory of cognitive development (1929) and Bronfenbrenner's ecological systems theory (Bronfenbrenner, 1979; Bronfenbrenner & Morris, 1998). Both postulate a cognitive change at the transition from preschool to school age. So far, no analyses on the cognitive structure and its stability around the passage from kindergarten to elementary school have been done.

Strengths and Limitations

Sensory discrimination questions have historically been investigated primarily in the auditory modality using small samples (Acton & Schroeder, 2001). Our study is therefore one of the few sensory discrimination examinations to focus on the visual and haptic modalities, using a large sample ($N = 1{,}330$), which probably results in more precise score estimates than in previous examinations.

Special mention should also be made of the age of the sample used in the present study. The age range of 5 to 10 years has so far been neglected in research about sensory discrimination and its correspondence with intelligence. In fact, the only other study that included sensory discrimination experiments with children of this age range was Spearman's (1904). However, Spearman's sample consisted of 36 children aged 5 to 10 years with 1–9 children per age group. Our examination leads to a gain of knowledge regarding the structure of intelligence in the earlier age bracket covering preschool and the first school years, as well as how it changes over time.

As already mentioned above, one limitation of this study is the rather small factor loading of the haptic discrimination on the general sensory discrimination as well as on the general intelligence factor. This is due to weak intercorrelations between haptic discrimination and the other variables. A possible explanation for this finding comes from Spearman (1904) himself. It was his contention that some senses convey the stimulus to the brain in an almost purely mechanical manner (e.g., touch) whereas others involve more cognitive processing (e.g., sight). Future studies should focus on "more cognitive" sensory discrimination tests when building a general sensory discrimination factor.

Conclusions and Future Prospects

In conclusion, the correlation of general discrimination and intelligence should be further examined. There are very few investigations on this topic. Furthermore, it would be interesting to more include psychophysiological measures to examine the relationship of the correlation, also proposed by Deary (2000a,b) and Deary et al. (2004). It is still unclear why the correspondence between general discrimination and general cognitive ability is high. To date significant correlations between sensory discrimination and intelligence have usually been seen as support of the thesis that intelligence is based on putative basic processes, such as processing speed, accuracy, efficiency, and even sensory discrimination. Future studies should examine whether this is the case or whether other factors – for example, common biological limitations or shared higher-level requirements such as attention or motivation – are responsible for the significant relationship (Deary et al., 2004). One rare study that has looked into this question is Bazana and Stelmack's (2002): They found a relationship between auditory discrimination ability and intelligence that could not be explained by response strategy, testtaking ability or attention deployment. Nevertheless, these findings await replication, and exploration of other sensory modalities seems warranted.

A deeper exploration of the general sensory discrimination factor would also be interesting, as the composition of

[3] Supplementary analyses, not presented in this context, point to a decline in the average correlations of the cognitive subscales and factor loadings as well as explained variances of the g from the youngest to the oldest age group. These results couldn't be explained by reliability differences or restriction of range and point to an interesting direction for future work.

the construct has received little attention. Spearman (1904) originally used in an experiment with preparatory school children one sensory modality (auditory), in an experiment with village-school children three sensory modalities (visual, auditory, and haptic) to construct the discrimination factor. In the latter experiment he wanted to test his hypothesis with as wide a range of sensory types as possible concerning their directness to the senses. His justification of his choice was that the other senses (taste, smell, pain, heat, cold) "do not admit of such practicable or satisfactory examination; also, probably on this account, they have as yet been investigated very incompletely, and therefore do not form a good unequivocal foundation for research of more advanced order" (p. 241). More recently there have been studies focusing on the correlation of alternative discrimination capacities such as tactile discrimination (Li et al., 1998) or olfactory discrimination (Danthiir et al., 2000) with g. Both studies found evidence for significant associations with general intelligence. In contrast, studies that explored the correspondence of haptic discrimination with g found no relation; nor was correspondence found with other sensory discrimination measures (Deary, 2000b; Deary et al., 2004). These findings raise the question of what general sensory discrimination really is – that is, from which sensory discrimination capacities can a general factor be constructed – and how diverse kinds of general sensory discrimination factors (e.g., unimodal vs. multimodal) correspond with g.

We end with possible practical implications of the finding of strong correspondence between general intelligence and general sensory discrimination. Though the cause of the high correlation of the constructs is not yet fully understood, sensory discrimination scales might be used in the future as the basis of new intervention approaches. An example is Lawton's (2007) training study in which inefficient readers in grades 2 and 3 were trained in direction discrimination, which resulted in significant improvements in reading efficiency and fluency. It remains to be seen if other specific cognitive abilities or even general intelligence can be enhanced when cognitive capacities such as sensory discrimination are trained.

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