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# Perceptual identification across the life span: a dissociation of early gains and late losses

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**Abstract** The age-correlated gains and losses in visual identification under backward pattern masking were studied in a representative sample of 226 individuals ranging from 6 to 88 years of age. Participants identified masked symbols at leisure under high and low stimulus quality and at varying Stimulus Onset Asynchronies. Performance increased from childhood to early adulthood and then decreased, describing the common inverted U-shaped function. However, measures of general processing speed accounted for the gains in childhood and adolescence but not for losses in older age. This asymmetry between child development and aging is inconsistent with general-factor lifespan theories of cognitive development and suggests that specific mechanisms underlying visual identification during child development and aging are different.

## Introduction

Throughout life our interactions with the environment rely on veridical information about the outside world. In the very beginning we possess only an elementary set of perceptual abilities. In early life this rudimentary set becomes refined by maturation and by our interaction with the environment until our perceptual capacities reach its highest level of sophistication in early adulthood. However, soon after the zenith human visual information processing starts to be affected by aging (for reviews see Faubert, 2002; Spear, 1993). This pattern of performance is in accord with common views of the life span development of basic information-processing mechanisms as an inverted-U-shaped pattern of rise and fall (e.g., Belmont, 1996; Dempster, 1992).

Both developmental psychology and aging research have put the emphasis on higher cognitive abilities (e.g., DeLuca et al., 2003; Diamond, 2002; Li et al., 2004; Salthouse, 1985, 1996; Verhaeghen & Cerella, 2002) or basic sensory/sensorimotor processes (see e.g., Li & Lindenberger, 2002 for a review). Relatively speaking, the development and aging of perceptual functions are studied less. As for aging effects, the main question is as to what perceptual abilities are or are not influenced by aging, and why (see Faubert, 2002). As for childhood development, a major focus of research is on the neural mechanisms underlying perceptual developmental and how it is affected by visual experience.

Hence, most studies explore either child development or aging separately, so that there is a lack of studies investigating representative samples across the human life span (see Bialystok & Craik, 2006, for review). As a consequence, although the inverted U-shaped development in all kind of skills is very well documented (e.g., Belmont,

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1996; Dempster, 1992), it is not clear whether the resemblance in behavioral performance observed in childhood and late life are actually caused by the same underlying mechanism. General-resource accounts (e.g., Cerella & Hale, 1994; Kail & Salthouse, 1994) claim that this is exactly the case: what is gained in processing efficiency through development from childhood to adolescence is lost through aging. However, whether or not rise and fall of cognitive abilities are mere mirror images of each other is still an open question.

To address this issue it is necessary to adopt a lifespan perspective that aims at identifying similarities and differences between the mechanisms contributing to child development and aging (Baltes, Staudinger, & Lindenberger, 1999; Bialystok & Craik 2006). Regarding visual information processing, Hommel, Li, and Li (2004), for example, investigated visual search from 6 to 89 years. They showed that there are indeed some general similarities in childhood and late life performance, but that there are also strong indications of processes specific to the two life periods, which is inconsistent with single-factor approaches of life span development.

The present study applied the lifespan perspective to early perceptual processes by investigating the impact of visual backward masking on stimulus identification as a function of age. Visual backward masking refers to the phenomenon that the visibility of a target stimulus can be strongly reduced when it is followed in time by a mask stimulus (see Breitmeyer & Ogmen, 2000). It is rather difficult to derive a coherent picture of masking effects during childhood, because the age groups investigated differ from study to study. However, some studies seem to suggest that children around 10 years of age show the best performances, followed by adolescents, while younger children are doing worst (Avant, Lyman, Skowronski, & Millsbaugh, 1977; Blake & Vingilis, 1977; Lawrence, Kee, & Hellige, 1980; LeBlanc, Muise, & Blanchard, 1992; Nettelbeck & Wilson, 1985). Studies comparing younger and older adults are also rather rare. Earlier findings suggesting increased masking effects in late life (Hertzog, Williams, & Walsh, 1976; Kline & Birren, 1975; Walsh, 1976) were confirmed only recently (Atchley & Hoffman, 2004).

Although interesting in their own right, all of these studies investigated development and aging separately. In the present study, we examined a representative population-based lifespan sample, which allowed us to directly compare performance in childhood, adulthood, and late life. In particular, we assessed perceptual performance under visual masking in the age range from 6 to 89 years. In the masking task, participants were asked to identify visually masked symbols that were either of low or high stimulus contrast. This manipulation was assumed to affect

stimulus quality, that is, the quality of the raw data available for perceptual operations. Processing limitations in perceptual identification were manipulated by varying the Stimulus Onset Asynchrony (SOA) between the to-be-identified visual target stimulus and the following pattern mask. Based on the available evidence, we assumed an inverted U-shaped performance pattern: identification performance should increase from childhood to adulthood and then decrease. Along the same lines, the impact of SOA should be more severe for the very young and the very old, as compared to young adults. For reasons that are unrelated to the present study, we also manipulated the set size, that is, the number of possible target alternatives, which could be two or four. However, for comparison reasons, we always report the outcomes for the same two target stimuli (i.e., both targets from the two-alternative set and the two corresponding targets from the four-alternative set).

Apart from perceptual performance, we also measured visual acuity of the participants and their general processing speed (simple reaction times, RTs). The former was used to control for individual differences in basic sensory acuity. The latter was meant to explore to which extent general speed of performance can account for masking performance across the life span. General-resource theories of life span development (e.g., Kail & Salthouse, 1994) predict that general performance speed should account for performance on both ends of the life span in more or less the same way. This is because they consider all performance measures to strongly depend on the same common factor and rise and fall to be mere mirror images. We test this notion by correlating simple RTs with masking performance. If this view is correct, general performance speed should correlate to the same degree with masking performance at both ends of the life span. By contrast, if different factors are responsible for the increase in identification performance during childhood and adolescence, on the one side, and the decline in performance during later life, on the other side, then one would expect general performance speed to be coupled more tightly to one or the other end of the life span (see below), resulting in high correlations on the one end of the life span and in low correlations on the other.

Notice that we opted for a rather coarse measure of performance speed. Simple RTs assess both perceptual and motor aspects of performance. They are not a standard measure of information processing usually used in studies on the processing speed theory, as for example the digit symbol substitution test (e.g., Salthouse, 1993; Lindenberger, Mayr, & Kliegl, 1993). Our rationale for this decision was that a measure covering the whole spectrum of human information processing should be more sensitive to any differences in correlation between early and late life. Evidently, this choice entails that we cannot draw strong

conclusions about the information processing speed account as such. Rather than questioning the validity of processing speed as an important factor for developmental changes on both ends of the life span, we intend to explore commonalities and differences in development and aging. We expected that correlations between masking performance and simple RT are higher during childhood and adolescence than during later life. Our expectations were based on Baltes's lifespan approach (Baltes, 1997; Baltes, Reese & Lipsitt, 1980). Baltes et al. suppose that gains in early life reflect improved neural communication, whereas the decline during later life rather reflects experiential influences and greater reliance on compensatory strategies. We assumed that factors concerning the development of the neural communication affect to a much larger extent all aspects of human performance than factors that are heavily determined by top-down processes (e.g., strategies, expectancies, familiarity).

## Methods

### Participants

To obtain a representative population-based lifespan sample, the parent sample of our study was randomly drawn from a list of 1,920 individuals (age ranged from 6 to 89 years) which was provided by the Berlin City Registry. The sample was stratified by age and sex. Because of rapid changes in cognitive development from age 6 to 15, one-year age bins were used for this range. In view of the developmental stability that is manifested in late adolescence and adulthood, 11 four-year age bins were used for the age range from 16 to 59. Finally, in light of data showing rapid age-related declines in many domains of cognitive functioning, 10 three-year age bins were used for the age range from 60 to 89. To recruit participants, a total of 1,873 invitation letters were sent, and a total of 356 individuals agreed to participate in the study. Hence, the participation rate for the entire sample is 19%. It is highest for individuals in the age range from childhood to early adolescence (45.7%), followed by individuals in the range from late adolescence to middle adulthood (19.9%), and was lowest for individuals in the old adulthood (10.5%).

Participants were screened for severe health problems that would interfere with the testing, as well as for psychological, and psychiatric problems. A complete psychometric battery of fluid and crystallized intelligence was administered (for details see Li et al., 2004). The tests showed that the older adults of the sample remained in high functioning of crystallized intelligence. The older participants of our sample were, thus, similar to other healthy aging samples.

Of the 356 participants who initially agreed to participate, some did not attend all measurement sessions. Excluding these participants and those for which some or all data from the masking task were missing, the effective sample in our analyses included 226 participants in 31 age bins. These participants were further subdivided into ten age groups. The result shown in Table 1 are based on groups of 6–8, 9–10, 11–14, 15–22, 23–33, 34–44, 45–55, 56–66, 67–77, and 78–88 years ( $M_s = 7, 10, 13, 17, 28, 39, 50, 62, 72, \text{ and } 82$  years), each including 15 to 29 participants. Evidently, small age ranges of 2–3 years across the whole life span—each including a comparable number of participants—would have been preferable. The ten age groups used in the present study reflect a compromise between theoretically reasonable age ranges and comparable group sizes. However, given that the variance in performance does not seem to be tremendously different across the ten age groups (see Table 1), we are confident that the difference in the size of the age ranges does not influence the results.<sup>1</sup>

### Apparatus and stimuli

The experiment was controlled by a custom-made program running on standard PCs. In the identification task, participants responded by pressing two or four horizontally arranged keys (depending on the stimulus set) on a standard computer keyboard. In the simple RT task, responses were performed by touching a touch-sensitive metal plate with the index finger of the dominant hand.

Stimuli were presented on standard computer monitors. The background screen was black (all colour guns set to zero) and the target letters were either bright-white (high stimulus contrast; all colour guns set to maximum intensity) or dark grey (low contrast; all colour guns set to about 35% of maximum intensity); masks were always bright-white. The two symbols # and þ, and the four symbols #, þ, &, and æ, served as targets in the two-alternative and the four-alternative condition, respectively. The target appeared at the centre of the screen and subtended approximately  $0.5^\circ \times 0.5^\circ$  of visual angle. The pattern mask consisted of the four superimposed symbols M, 8, ¥, and }, presented at the same spatial location as the target stimulus.

<sup>1</sup> As regards the effect of the difference in age range for young and old participants on the correlations reported below, notice that for the correlation analysis we collapsed several age bins to form larger groups. The three groups we analysed represent the entire childhood/adolescence, young and older adulthood, respectively. It is, thus, rather improbable that range restrictions resulted in statistical artefacts.

**Table 1** Simple response: RT Medians (RT, in ms) and Standard Deviations of RTs (SD) as a function of Age Group

Age group (years)	n	Simple response	Masked identification [ $d'$ ]													
			SOA 28 ms				SOA 56 ms				SOA 112 ms					
			Low contrast		High contrast		Low contrast		High contrast		Low contrast		High contrast			
Set 2	Set 4	Set 2	Set 4	Set 2	Set 4	Set 2	Set 4	Set 2	Set 4	Set 2	Set 4					
1	6–8	15	RT 490	-0.26 (0.45)	0.14 (0.68)	0.03 (0.46)	0.29 (0.58)	0.22 (0.5)	0.35 (0.45)	0.71 (0.76)	1.4 (0.91)	1.16 (0.79)	1.93 (1.22)	1.86 (1.24)	2.5 (1.37)	SD 111
2	9–11	24	RT 358	-0.04 (0.41)	0.28 (0.57)	0.31 (0.56)	0.4 (0.73)	0.31 (0.45)	0.16 (0.99)	1.33 (1.04)	1.17 (0.8)	1.84 (1.08)	2.34 (1.14)	2.12 (0.98)	3.15 (1.26)	SD 84
3	12–14	24	RT 315	-0.13 (0.41)	0.12 (0.57)	0.34 (0.63)	0.46 (0.45)	0.51 (0.51)	0.55 (0.45)	1.65 (1.12)	2.49 (1.36)	2.26 (1.11)	2.94 (1.34)	2.26 (0.99)	3.25 (1.16)	SD 72
4	15–22	19	RT 323	-0.24 (0.36)	-0.07 (1.07)	0.42 (0.68)	0.28 (0.61)	0.33 (0.73)	0.54 (0.62)	1.69 (1.07)	1.97 (1.34)	2.06 (1.32)	2.83 (1.61)	2.32 (1.04)	3.1 (1.23)	SD 59
5	23–33	23	RT 300	-0.18 (0.56)	0.36 (0.35)	0.8 (0.9)	0.71 (0.48)	0.59 (0.79)	0.54 (0.66)	2.13 (0.95)	2.72 (1.39)	2.35 (0.92)	3.04 (1.36)	2.79 (0.8)	3.86 (0.89)	SD 93
6	34–44	24	RT 303	-0.04 (0.43)	0.24 (0.52)	0.6 (0.52)	0.5 (1.05)	0.26 (0.59)	0.45 (0.61)	1.58 (1.33)	2.06 (1.41)	2.2 (1.09)	2.24 (1.31)	2.23 (1.12)	3.39 (1.22)	SD 69
7	45–55	26	RT 318	-0.18 (0.48)	0.12 (0.79)	0.42 (0.8)	0.42 (0.86)	0.33 (0.41)	-0.02 (1.11)	1.47 (1.12)	1.4 (1.23)	1.43 (0.99)	1.35 (1.43)	1.87 (1.01)	2.64 (1.44)	SD 61
8	56–66	29	RT 356	0.12 (0.4)	0.09 (0.77)	0.39 (0.56)	0.32 (0.81)	0.01 (0.48)	0.1 (0.77)	1.13 (1.01)	1.29 (1.53)	1.35 (1.29)	1.36 (1.95)	2.12 (1.17)	2.49 (1.79)	SD 92
9	67–77	26	RT 375	-0.03 (0.47)	0.08 (0.79)	0.02 (0.63)	0.46 (0.49)	0.23 (0.5)	-0.13 (0.98)	0.87 (1.11)	0.93 (0.87)	0.56 (0.83)	0.88 (1.03)	1.84 (1.29)	2.37 (1.45)	SD 89
10	78–88	16	RT 399	0.03 (0.42)	0.1 (0.51)	0.21 (0.46)	0.25 (0.55)	0.25 (0.68)	0.08 (0.57)	1.07 (1)	1.38 (1.53)	0.54 (0.66)	0.66 (0.81)	1.23 (1.44)	2.09 (1.61)	SD 104
Total	6–88	226	RT 354	-0.09 (0.45)	0.15 (0.69)	0.37 (0.67)	0.42 (0.7)	0.3 (0.58)	0.25 (0.8)	1.38 (1.12)	1.67 (1.37)	1.6 (1.2)	1.95 (1.58)	2.09 (1.14)	2.9 (1.44)	SD 83

Masked Identification: Mean  $d'$ 's (and Standard Deviations of  $d'$ 's) as a function of SOA, Stimulus Contrast, Stimulus Set Size, and Age Group

## Procedure and design

### Identification task

Participants were instructed to identify the alphanumeric target letter by an unspeeded keypress and to guess when uncertain. Each trial began with a blank interval of 2,000 ms. Thereafter, a fixation square encompassing the target and mask location was presented for 500 ms. After the fixation square disappeared, the screen remained blank for another 500 ms. Then, the target letter was presented. After an SOA of 28, 56, or 112 ms the mask replaced the target and stayed in display until response. 500 ms after mask onset, the display prompted the participant to respond (In case of the four-alternative condition: “Which target letter has been presented? #, &, æ, or þ”). In case of an error an error feedback display was presented for 1,000 ms. Viewing distance was about 80 cm.

We manipulated three factors independently: Stimulus Contrast (high vs. low contrast), SOA (28 vs. 56 vs. 112 ms), and Stimulus Set Size (2 vs. 4 possible stimuli). SOA and Stimulus Contrast were manipulated within blocks, Stimulus Set Size between blocks. Participants alternated between blocks with 2 and blocks with 4 target stimuli. Before each test block 14 warm-up trials were presented. The test blocks comprised 12 trials with two alternatives and 24 trials with four alternatives, and each of these two block types was presented three times.

### Visual acuity test

Visual acuity was measured in Snellen decimal units at two different distances using standard reading tables (Geigy, 1977). Distant visual acuity was assessed binocularly with reading tables presented at 7.5 meters (the letter reading table) and 5 meters (the Landolt rings). Close visual acuity was measured by a table with printed text and a table with Landolt rings at a 30-cm reading distance. The measurements were taken both with and without vision corrections. The analyses reported in this article were based on corrected vision. We computed a summary measure, or visual acuity index (VAI), that was based on the composite score of the participant’s corrected distant vision and close vision.

In addition, we assessed participants’ performance in a *simple reaction time task*. Participants were asked to respond as fast as possible by pressing the key of a response device as soon as any stimulus (either a square or a circle) appeared on the center of the screen. The simple RT task comprised 30 trials, half performed with the left and half with the right index finger. A trial began, after an inter-trial interval of 1,000 ms, with the presentation of a central fixation cross for 500 ms. The fixation cross was

then followed by a random delay interval from 500 to 3,499 ms, after which a stimulus was presented for 1,500 ms on the screen. Responses were valid only if made during the stimulus duration. Viewing distance was about 80 cm.

## Data analysis and results

Mean percent correct [ $p(c)$ ] was computed for each combination of Age Group, Stimulus Set Size, SOA, and Stimulus Contrast. In order to make performance measures from the two set size conditions comparable, we computed  $d'$  prime ( $d'$ ) measures. For the two-alternative blocks, we used the standard formula given by Green and Swets (1966):

$$d'(x) = z(x) \times \sqrt{2},$$

where  $x$  is  $p(c)$ .

For the four-alternative blocks, we used the algorithm from Smith (1982) based on the Luce choice model:

$$d' = K \times \ln((M - 1) \times p(c) / (1 - p(c))),$$

where  $K = 0.86 - 0.0085 \times \ln(M - 1)$ .

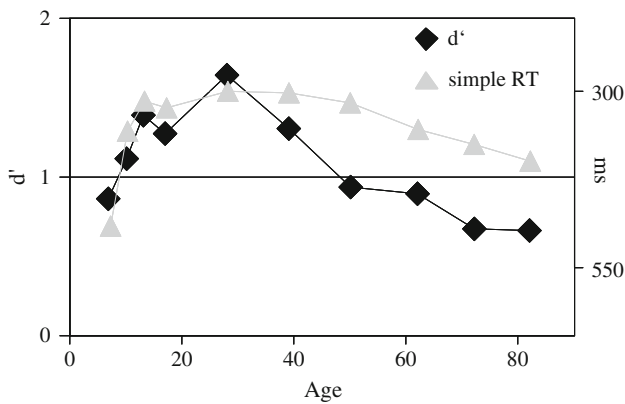
The estimates calculated with this algorithm fit well with the table for estimating  $d'$  from  $p(c)$  for M-alternative forced choice (M-AFC) tasks reported in Macmillan and Creelman (1991).

The  $d'$  values underwent two analyses of variance (ANOVA). One ANOVA was run with Stimulus Contrast, SOA, and Stimulus Set Size as within-participants factors and Age Group as a between-participants factor. Secondly, the same ANOVA was run with the VAI as covariate. Table 1 provides an overview of the data.

Moreover, mean simple RTs were computed for all age groups and correlated separately for three age bins (groups 6–22, 23–55, 56–88) with individual  $d'$ ’s of the masking task. For the sake of simplicity,  $d'$  data was collapsed across the factor Stimulus Set Size. (However, the pattern of results reported below was extremely similar when correlations were computed separately for the two set sizes, demonstrating that set size does not affect correlations between  $d'$ ’s and simple RTs.) We used three age bins only in order to ensure the statistical reliability of the correlations.

The ANOVA including Stimulus Contrast, SOA, and Stimulus Set Size as within-participants factors and Age Group as a between-participants factor yielded four significant main effects. Participants showed better performance with increasing SOA,  $F(2,432) = 738,15$ ,  $P < 0.001$ , better performance with high contrast stimuli than with low contrast stimuli,  $F(1,216) = 447,62$ ,  $P < 0.001$ , and better performance in four-alternative than





**Fig. 1** Mean masked identification performance (in  $d'$ ) by Age Group and, for purposes of comparison, mean simple RTs by age group. Y-axis reversed for simple RTs

in two-alternative blocks,  $F(1,216) = 58.84, P < 0.001$ .<sup>2</sup> The main effect of Age Group, ( $F(9,216) = 6.99, P < 0.001$ ), indicates that the cross-sectional age gradients of  $d'$ 's increased with increasing age from 6 years up to 23–33 years and decreased with age from there on. Figure 1 shows  $d'$ 's as a function of Age Group. For purposes of comparison, the figure also shows mean simple RTs (Notice that the Y-axis reversed for simple RTs). The interactions of SOA  $\times$  Age Group ( $F(18,432) = 6.32, P < 0.001$ ), SOA  $\times$  Stimulus Set Size ( $F(2,432) = 33.10, P < 0.001$ ), SOA  $\times$  Stimulus Contrast ( $F(2,432) = 74.67, P < 0.001$ ), SOA  $\times$  Contrast  $\times$  Age Group ( $F(18,432) = 4.27, P < 0.001$ ), Stimulus Set Size  $\times$  Contrast ( $F(1,216) = 15.83, P < 0.001$ ), and SOA  $\times$  Stimulus Set Size  $\times$  Contrast ( $F(2,432) = 14.61, P < 0.001$ ) were also significant. We included the factor Set size—which was unrelated to the present study—into the ANOVAs in order to demonstrate that it does not interact with Age Group, but we will not consider this factor any further.

Including the VAI as a covariate did not change the test statistics: The VAI did not yield a significant main effect, nor did it take part in a significant interaction. Moreover, with the VAI as a covariate the ANOVA yielded the same

<sup>2</sup> As already mentioned, from the four-alternative set we analysed only those trials in which the same stimuli were presented which also pertained to the two-alternative set. Let's call these two stimuli target stimuli. However, it turned out that the two additional symbols used in the four-alternative set (let's call them filler stimuli) were somewhat simpler to detect, making correct guesses of the target stimuli more likely. This is because, "knowing" that the probability not to recognise the two filler stimuli is rather low (simply because they are rather easy to detect), participants probably tended to pick one of the two difficult symbols (target stimuli), if they had to guess. This increased the chance probability of the two target stimuli by an unknown amount. As a consequence, using the aforementioned formula to calculate  $d'$ , participants' performance was better in the four-alternative than in the two-alternative condition, although the same stimuli were analysed.

**Table 2** Spearman rank correlations between simple RTs and mean  $d'$  for three age bins as described in the text

Age bin		6–22	23–55	56–88
SOA 28 ms	Low	–0.27	–0.16	–0.03
	High	–0.24	–0.12	–0.05
SOA 56 ms	Low	–0.047	0.09	–0.01
	High	–0.51	0.02	–0.04
SOA 112 ms	Low	–0.39	–0.04	–0.03
	High	–0.36	0.07	0.008
Collapsed		–0.49	0.004	0.01

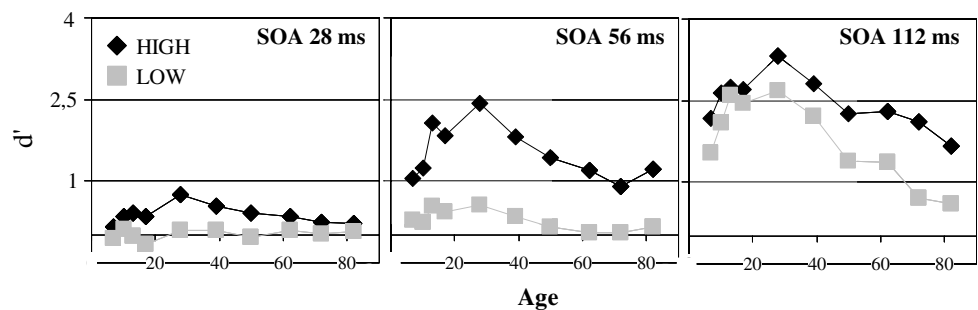
The correlations are shown separately for the two factors SOA (28, 56, 112 ms) and Stimulus Contrast (high, low) and collapsed across all conditions

levels of significance for the other main effects and interactions.

The Spearman rank correlation between  $d'$ 's and simple RTs was low for all conditions in which the  $d'$  was very low, irrespective of the three age bins we analyzed (see Table 2; both 28 ms SOA conditions and the low contrast  $\times$  56 ms SOA condition). Evidently, this is because  $d'$  does not vary enough to allow for high correlations. More interesting are the results of the other conditions (in Table 2 shaded in grey), in which the visibility of the target symbols was higher (both 112 ms SOA conditions and the high contrast  $\times$  56 ms SOA condition). In these conditions correlations are high for the youngest age bin ( $r$ 's between –0.36 and –0.51), i.e. during childhood and adolescence, but virtually zero for the other two age bins, i.e. for both younger adults ( $r$ 's between –0.04 and 0.07) and older adults ( $r$ 's between –0.04 and 0.008). The correlations between the overall  $d'$ 's and simple RTs indicated in the last row of the table corroborate this finding. We also computed correlations for the age group 6–11 years. The correlation coefficients are very similar to the group of 6–22 years reported in Table 2. In the two 112 ms SOA conditions and in the high contrast  $\times$  56 ms SOA condition  $r$ 's were between –0.24 and –0.35. We are, thus, confident that the strong correlation holds for the entire span from early childhood to late adolescence.

To further substantiate this result, we ran two separate ANOVAs for the youngest age bin (6–22 years) and for the remaining bins (23–88 years). The ANOVAs included the same factors as the omnibus tests described above. However, this time we included simple RTs as a covariate. The most important outcomes can be summarized as follows. With respect to young and old adults, simple RTs did not yield a significant main effect ( $F(1,137) = 0.13, P = 0.73$ ), nor did simple RTs take part in any significant interaction. Instead, the main effect of Age Group

**Fig. 2** Mean masked identification performance (in  $d'$ ) by Age Group, SOA, and Stimulus Contrast (high, low)



( $F(5,137) = 8.55$ ,  $P < 0.001$ ) and the interactions as described above were significant. By strong contrast, with respect to children and adolescents, the main effect of simple RTs was highly significant ( $F(1,77) = 8.34$ ,  $P < 0.01$ ), so were interactions of simple RTs with the other variables. In this ANOVA, neither the main effect of Age Group ( $F(3,77) = 0.63$ ,  $P = 0.6$ ) nor any interactions of Age Group reached significance. In other words, the increase in identification performance in the masking experiment across childhood and adolescence is completely accounted for by factors measured with simple RTs, whereas simple RTs fail to capture the factor responsible for the decline in performance across adulthood and old age.

## Discussion

The present study shows that perceptual abilities increase during childhood and adolescence and decrease during early and late adulthood (see Fig. 1). Our findings are thus consistent with the common finding that cognitive performance across the lifespan follows an inverted U-shaped function. However, our findings do not fit with the idea that early cognitive gains and late losses reflect changes in the same kind of mechanism. Increases in performance during young age were entirely accounted for by simple RTs. By contrast, simple RTs were unrelated to the decline in perceptual performance in old age. Hence, our findings demonstrate that, as concerns visual identification of masked stimuli, rise in performance during childhood and fall in later life are not mere mirror reflections of each other. This suggests that single-factor accounts of lifespan development (e.g., Kail & Salthouse, 1994) are incomplete in explaining changes during a considerable part of the age range.

The present study is part of a major project investigating the relationship between elementary perceptual and cognitive processes and intellectual abilities across life span development (see Li et al., 2004). As such, the study is foremost meant to provide an informative basis for future research. However, we see several—not mutually exclusive—possibilities why there is a breakdown in the

correlation between simple RTs and perception under backward masking in later life.

The first account bears on the notion of neural noise as defined by information processing approaches to human development. On both ends of the lifespan, information processing approaches have related changes in performance in a number of tasks, from simple sensory-motor to more cognitive tasks, to a reduction/increase of neural noise in the sensory-motor system (e.g., Kail, 1997; MacDonald, Nyberg, & Bäckman, 2006; Li, von Oertzen, & Lindenberger, 2006; Plude, Enns, & Brodeur, 1994; Wickens, 1974). The change of the signal-to-noise ratio during childhood has been attributed to the progressive myelination of the axons in the central nervous system (e.g., Klingberg, Vaidya, Gabrieli, Moseley, & Hedehus, 1999; Paus et al. 1999). Such an enhancement of the myelination is expected to influence all aspects of sensory-motor behavior alike, that is, sensory-motor translations as assessed with simple RTs as well as purely perceptual functions as assessed with masked identification performance. The finding that, for children and adolescents, the effect of age on masked identification is accounted for by simple RTs is thus in line with the idea that a global improvement of the signal-to-noise ratio is the common factor behind the improvement of both simple RTs and masked identification performance.

As concerns the other end of the lifespan, there is evidence that the effect of anatomical neuronal loss is rather small during normal aging and that, accordingly, cognitive and sensorimotor deficits are more likely to be due to neurochemical shifts in relatively intact neural networks (Morrison & Hof, 1997). These changes in later life have recently been associated to a decreased processing robustness, an aspect of intraindividual dynamics that also reflects the signal-to-noise ratio (e.g., Li, Lindenberger, & Sikström, 2001; Li et al., 2006; MacDonald et al., 2006). However, it has been suggested that a lack of processing robustness is rather indicated by intraindividual trial-by-trial performance fluctuations. Li et al. (2004) showed that, in late adulthood and old age, processing robustness added at least as much unique variance as processing speed in predicting fluid intelligence. Moreover, processing



robustness predicted old people's chronological age above and beyond processing speed. Importantly, these effects were unique to the senescence portion of the lifespan. Our results are in accordance with these findings in that they show that the specific aspects of intraindividual dynamics assessed by mean simple RTs do not predict perceptual identification performance on both ends of the lifespan, but only during childhood and adolescence.

Secondly, it is possible that the results are due to a general uncoupling of motor and perceptual abilities in later life. As mentioned in the introduction, simple RTs are a rather heterogeneous measure of processing speed, assessing both perceptual and motor components of speed. Since aging influences both motor and perceptual performance, motor changes could have an impact on simple RTs without affecting perception. Or, conversely, changes in the visual system might affect perception under backward masking conditions without affecting simple RTs to high contrast stimuli. Both these possibilities would result in a decrease in correlation between simple RTs and perception under backward masking. Notice that single factor accounts of human development are not easily reconcilable with the notion that the decline in performance in later life takes place in uncoupled components.

Third, another factor possibly responsible for the differences in rise and decline of performance across lifespan is the age-related regression of central or attentional factors. Atchley and Hoffman (2004) investigated the influence of spatial attention and stimulus contrast on visual masking in younger and older adults. They demonstrate that the interaction of peripheral and central processes contribute to the effect of masking, with older adults being particularly susceptible to the effects of attentional processes because peripheral changes impoverish the information. In other words, due to peripheral factors older adults seem to have a poorer representation of the external stimulation, but they can make up for this disadvantage by allocating more attention. However, in the absence of focused attention, older observers are unable to maintain the same level of accuracy as younger observers.

This interpretation is in accordance with the pattern of results illustrated in Fig. 2. The figure shows identification performance as a function of SOA, Stimulus Contrast and Age Group. The performance of older adults matches the performance of children in almost all conditions except for the longest SOA and stimuli of low contrast (lower panel, grey line). For the longest SOA, the performance of children and adolescents was very similar for low and high contrast stimuli. By contrast, as for low contrast stimuli, older adults lag behind children and adolescents. In other words, children and adolescents were able to use the longer SOA to compensate for the poorer quality of the stimulation but older adults were not.

Interestingly, the consideration that early gains reflect improved neural communication but late losses attentional restrictions fits nicely with Baltes's lifespan approach (Baltes, 1997; Baltes et al., 1980). Baltes et al. suppose that development during childhood and adolescence are driven primarily by biological factors, or cognitive mechanics. By contrast, performance differences in later life—although also supposed to reflect a decline of cognitive mechanics and neurobiological processes—are rather due to a greater reliance on compensatory strategies. Similarly, Plude et al. (1994) have hypothesized that improvements in selective attention during childhood reflect the myelination of neural pathways, whereas the decline during later life reflects more experiential influences, in addition to declines in neurobiological factors.

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**Note added in proof:** This study is part of the CoOP-MIND Study, a collaborative research project (investigating the CoOperation and intercorrelation between a broad class of elementary Perceptual and cognitive processes, such as Memory, visual search, and choice reactions, and psychometrically defined INtellectual abilities across life span Development) between the Max Planck Institute for Human Development and the Max Planck Institute for Psychological Research. In addition to the authors who were directly involved in the present study, other members of the research project are G. Aschersleben, F. Miedreich, and W. Prinz from the Max Planck Institute for Psychological Research and P. B. Baltes and U. Lindenberger from the Max Planck Institute for Human Development. We thank Annette Rentz-Lühning and many other student assistants for help in collecting the data.

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