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Theoretical Notes

Incidental Learning and the Development of Selective Attention

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The incidental learning paradigm has provided two well-established findings concerning the development of selective attention: (a) The difference between central and incidental task performance *increases* with age, and (b) the correlation between central and incidental performance *decreases* with age. It has generally been assumed that these results reflect a developmental increase in the ability to process information selectively. In the present article it is argued that neither of these findings constitutes unambiguous support for the view that attentional selectivity improves with age. It is suggested that recent theory and research on capacity trade-offs in dual-task performance provide a potentially valuable alternative framework for understanding the development of attentional processes.

The incidental learning paradigm has provided two well-established findings concerning the development of selective attention: (a) The difference between central and incidental task performance increases with age (Druker & Hagen, 1969; Hagen, 1967; Hagen, Meacham, & Mesibov, 1970; Hallahan, Kauffman, & Ball, 1974; Maccoby & Hagen, 1965), and (b) the correlation between central and incidental performance decreases from positive at younger ages to negative at older ages (Druker & Hagen, 1969; Hagen, 1967; Hagen et al., 1970). It is common for researchers to interpret these findings as evidence for age-related changes in attentional processes. For example, Druker and Hagen wrote,

> The significant interaction between grade and type of recall [central vs. incidental] replicates a finding of earlier studies (Hagen, 1967; Maccoby & Hagen, 1965) and confirms the prediction that central and incidental information are processed differently at different ages. (p. 377)

Significant Age × Condition interactions were obtained in each of the experiments cited previously and, as in the case of the Druker and Hagen article, were interpreted as reflecting a developmental change in selective attention. It is important to note that a test of Age × Condition interaction is algebraically equivalent to a test of the effect of age on the difference between central and incidental learning.

The finding of a decrease with age in the correlation between central and incidental learning has also been taken as support for the view that attentional selectivity improves with age. Consider, for example, the argument presented by Hagen (1967):

> One would expect that, if the interaction between central and incidental information were such that the concentration on relevant cues resulted in an inability to concentrate on irrelevant cues, the correlation between performance on the two measures would be negative. Because this ability to attend selectively supposedly increases with age, one would expect this negative relation to increase with increasing grade level. (p. 691)

As demonstrated later, neither the age-related increase in the difference between central and incidental learning nor the decrease with age in the correlation between central and incidental learning provides unambiguous support for the view that attentional selectivity improves with age; in the final section of this article, an alternative strategy for investigating the development of selective attention is suggested.

Early work on age changes in incidental learning (Hagen, 1967; Maccoby & Hagen, 1965) discussed attentional development in the context of Broadbent's (1958) filter theory. It was hypothesized that the filtering mecha-

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Table 1
Mean Capacity Allocated to and Correlation Between Central and Incidental Tasks

μ_c	$\rho_{p,c}$	Task		r_{c_1,c_2}
		Central	Incidental	
4	.25	2.94	.99	.58
	.50	2.91	.97	.47
	.75	2.98	.94	.43
8	.25	5.99	2.05	−.03
	.50	5.99	2.00	.02
	.75	5.94	2.02	.17
12	.25	9.03	2.99	−.28
	.50	9.03	3.02	−.24
	.75	9.06	3.01	−.21

Note. Each value is based on 250 simulated subjects. μ_c = mean amount of capacity; $\rho_{p,c}$ = correlation between p and c; r_{c_1,c_2} = correlation between capacity allocated to the central and incidental tasks.

nism would become more efficient with age and that, as a result, the limited capacity channel would be processing relevant information a greater proportion of the time. The present analysis is based on a capacity model of attention (Kahneman, 1973; Norman & Bobrow, 1975), and therefore attentional selectivity is defined as the proportion of attentional resources allocated to the central task rather than the proportion of time the limited capacity channel is processing relevant information. Nevertheless, the arguments apply with equal force to an analysis based on a filter model.

Define P as the proportion of processing resources allocated to the central task, and define C as the total processing capacity. The resources allocated to the central task (C_1) and the incidental task (C_2) can be expressed as

$$C_1 = PC, \quad (1)$$

$$C_2 = (1 - P)C. \quad (2)$$

Accordingly, a developmental change in processing capacity would be reflected by age differences in C, whereas a developmental change in attentional selectivity would be reflected by age differences in P.

Assuming that performance is monotonically related to allocated resources, the difference between central and incidental performance should vary as a function of

$$\begin{aligned} C_1 - C_2 &= PC - (1 - P)C \\ &= C(2P - 1). \quad (3) \end{aligned}$$

Clearly, P and C are confounded: A developmental change in the difference between central and incidental performance could result from age differences in either C or P.

Neither does the finding of a decrease with age in the correlation between central and incidental performance necessarily indicate an age difference in P. To simplify the mathematics, the covariance rather than the correlation between central and incidental performance is derived. A simulation discussed later generalizes these findings to the more typical correlational measure. The covariance between resources allocated to the central and incidental tasks can be expressed as

$$\begin{aligned} \sigma_{c_1,c_2} &= E[(PC)(1 - P)C] - E(PC)E[(1 - P)C] \\ &= E(PC^2) - E(P^2C^2) - E(PC) \\ &\qquad \times [E(C) - E(PC)] \\ &= \sigma_{p,c^2} + \mu_p(\sigma_c^2 + \mu_c^2) - [\sigma_{p^2,c^2} \\ &\qquad + (\sigma_p^2 + \mu_p^2)(\sigma_c^2 + \mu_c^2)] - (\sigma_{p,c} + \mu_p\mu_c) \\ &\qquad \times [\mu_c - (\sigma_{p,c} + \mu_p\mu_c)] \\ &= \sigma_c^2(\mu_p - \mu_p^2 - \sigma_p^2) + \sigma_{p,c^2} - \sigma_{p^2,c^2} \\ &\qquad + \sigma_{p,c}\sigma_{p,c} - \mu_c(\mu_c\sigma_p^2 - 2\mu_p\sigma_{p,c} \\ &\qquad + \sigma_{p,c}), \quad (4) \end{aligned}$$

where σ_{p^2,c^2} is the covariance of P^2 and C^2, σ_{p,c^2} is the covariance of P and C^2, $\sigma_{p,c}$ is the covariance of P and C, σ_c^2 is the variance of C, σ_p^2 is the variance of P, μ_c is the mean of C, and μ_p is the mean of P. An inspection of Equation 4 reveals that although for certain combinations of parameter values the relationship between μ_c and σ_{c_1,c_2} is nonmonotonic over portions of the function, increases in μ_c are generally associated with decreases in σ_{c_1,c_2}. Therefore, the change in the correlation between central and incidental performance from positive at younger ages to negative at older ages could occur simply as a function of an increase with age in the average value of C.

The validity of the generalization from the covariance to the correlation between C_1 and C_2 was tested by the following simulation. The values of σ_c, μ_p, and σ_p were held constant at 1.0, .75, and .05, respectively, throughout the simulation. Three values of the correlation between P and $C(\rho_{p,c})$ were examined factorial to three values of μ_c; both P and C were sampled from normally distributed populations. The mean capacity allocated to the central and to the incidental tasks as well as the correlation between capacity allocated to these tasks is shown in Table 1. An inspection of Table 1 reveals that the difference between attention allocated to the central and incidental tasks increases with increasing μ_c, whereas the correlation between attention allocated to the central and incidental tasks decreases with μ_c. Thus, as the pattern of results typically obtained in an incidental learning study can be simulated by a model not assuming differences in P, it appears that these studies provide, at best, tentative support for the hypothesis that P changes with age.

This analysis is not meant to suggest that no valid inferences can be derived from incidental learning data. For example, the finding that older children and college students perform worse than elementary school children on the incidental task (Druker & Hagen, 1969; Hagen et al., 1970; Wagner, 1974) indicates a developmental increase in the ability to ignore irrelevant information. What is less clear is what happens from age 7 to age 11, at which point improvements in both central and incidental performance occur (Zukier & Hagen, 1978).

It may be fruitful to view incidental learning as one point on the continuum of differential payoffs: No payoff is expected for attending to the irrelevant stimuli. Few studies have addressed the problem of developmental changes in the ability to divide attention optimally between tasks that differ in payoff. Birch (1976) found no increase with age (from 7 years to 13 years) in the difference between primary- and secondary-task performance. On the other hand, Lane (1979) found a difference between primary- and secondary-task performance in none of the 7-year-old subjects, 30% of the 10-year old subjects, and in all of the college subjects. Although the performance of the 7-year-olds was clearly nonoptimal, the methodology used by Lane is only adequate to detect large deviations from optimal performance; the difference between primary- and secondary-task performance is not a sensitive measure of attention-allocation efficiency. For example, this measure does not allow one to differentiate between subjects who allocate their attention optimally and those who allocate too much attention to the primary task.

The concept of a performance operating characteristic (POC) introduced by Norman and Bobrow (1975) provides a coherent framework for analysis. A POC consists of a plot of performance on one task as a function of performance on another task when combined performance is at a maximum. As such, a POC traces the boundary of feasible joint performance; it extends from a point on the ordinate representing single-task performance on one task to a point on the abscissa representing single-task performance on a second task. In general, POCs are concave downward functions.

Navon and Gopher (1979) have shown that the optimal point (in terms of payoff) on the POC is the intersection of the POC and the "northeastern" most indifference curve, where an indifference curve is a set of points having equal utility or payoff. For example, if each unit of performance on Task A had a utility of six and if each unit of performance on Task B had a utility of three, the total utility would be equal to six times the score on Task A plus three times the score on Task B. A score of four on Task A in combination with a score of two on Task B would yield a total utility of 30; scores of two on Task A and six on Task B would also result in a utility of 30. The line consisting of points with utilities of 30 would be an indifference curve. All lines parallel to this one would also be indifference curves, and the point of intersection between the POC and the indifference curve farthest from the origin that intersects the POC would be the point on the POC at which the payoff is maximized. In this example, the utility of each additional unit of performance was constant; as a result, the indifference curve was a straight line. Nonlinear indifference curves occur when the marginal utility is variable (e.g., diminishing).

My belief is that the development of attentional processes can be studied more profitably in the context of recent theoretical advances in attention allocation (Kinchla, in press; Navon & Gopher, 1979; Norman & Bobrow, 1975; Sperling & Melchner, 1978) than by using the incidental learning paradigm. One might, for example, have subjects engage in dual-task performance under a variety of experimenter-defined payoffs. For each payoff condition, the optimal point on the POC could be determined from the relevant indifference curve and compared with the point at which subjects actually performed. Such an analysis would be sensitive to possible developmental differences in attention allocation and would provide a basis for investigating the processing differences underlying them.

In addition to the interpretational problems discussed in this article, the study of incidental learning is severely hampered by the fact that it is only possible to obtain one datum per subject in an incidental learning condition.

Thus, reliable data can be obtained only by averaging over many subjects. This makes it extremely difficult to test models of the processes because of the well-known problems of generalizing from group curves to individual curves. Indeed, the small model proposed in this article is best thought of as demonstrating that it is possible to develop a model consistent with available data that does not assume that attentional selectivity improves with age. Because of the problems of testing models using incidental learning data, no attempt to fit the model to data was made, and other researchers are not encouraged to do so. Rather, using a paradigm in which the relative importance of tasks is manipulated, it should be possible to obtain many data points per subject and to develop more rigorous models.

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