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On the hierarchical structure of the original Posner task

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Abstract

The investigation of the reaction times obtained by means of the Posner task for measuring the speed of the retrieval of long-term memory contents revealed a hierarchical structure. This investigation also extended to the rule identity condition included in the original Posner task in addition to the commonly known and utilized physical and name identity conditions. Physical identity reaction times, name identity reaction times and rule identity reaction times constituted three first-order factors. The correlations among these first-order factors gave rise to the general second-order factor. Furthermore, there was an additional investigation of the causal effects among the first-order factors. The results suggested the processing stimulated by the physical identity condition as the basic source that contributes directly to the processing stimulated by the name identity condition and indirectly to the rule identity condition. Additionally there was a unique contribution of the name identity condition to the rule identity condition.

Keywords: speed of processing, retrieval of information, confirmatory factor analysis, hierarchical model

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In 1967, a task for "the analysis of the depth of processing in simple classification" was published (Posner & Mitchell, 1967, p. 392). This task has become known as the Posner task for long-term memory retrieval of information. In the original experiment, pairs of items (letters, nonsense forms, digits) were presented to the participants who were supposed to respond as fast as possible by indicating either "same" or "different". In completing the trials of this task the participants had to perform according to different rules that constituted three experimental conditions. (1) Under the "physical identity" instruction they had to check whether the two items presented on a screen showed physical identity (e.g., A A). (2) The "name identity" instruction required the participants to compare the two items with respect to their semantic meaning. More precisely, either the same name (e.g., a A) or different names (e.g., a B) applied to both items. (3) Finally, there was the "rule identity" instruction that utilized the possibility to classify letters as vowels or consonants, i.e., the participants had to decide whether both items belonged to the same group. The depth-of-processing idea guiding Posner and Mitchell's work suggested that there are different levels of information processing. While the first level demanded mere processing of feature information in the sense of the "physical identity" instruction, the second level necessitated access to stored information, as is demanded by the "name identity" instruction. Finally, the "rule identity" instruction additionally required the recovery of rules and their application.

To a considerable extent, Posner and Mitchell's (1967) depth-of-processing idea is in line with another, even more influential notion in cognitive research, namely Craik and Lockhard's levels-of-processing model that was first published in 1972. According to this model, the accessibility of information stored in memory is considered a function of the depth of mental processing when storing information in memory. 'Deep' mental processing produces memory traces that are more elaborated, longer lasting, and stronger than those formed by 'shallow' mental processing. Furthermore, deep and shallow mental processing are proposed to represent two anchor points of a continuum. Hence, deep processing involves the identification and elaboration of semantic contents, linking contents and learnt items, and creating links for embedding new information in an already available web of information. In contrast, shallow processing is restricted to establishing links between one or a few obvious and easily accessible features of a learnt item and corresponding conceptual information in the web. As a consequence, information stored by deep mental processing can be accessed and retrieved in many ways, whereas only one or very few routes to access information exist for information stored by shallow processing. Finally, there are consequences with regard to the long-term availability of learnt items stored in long-term memory: the more links lead to a learnt item, the smaller the probability of losing access to this item in the long run.

In the years following the publication of the Posner task (Posner, Boies, Eichelmann, & Taylor, 1969; Posner & Mitchell, 1967), the research interest concentrated on the physical and name identity conditions whereas the rule-identity condition was neglected. It was Hunt (1978) who especially highlighted the importance of the qualitative difference between the mental processes underlying performance elicited by the physical- and name-identity instructions. According to Hunt, the physical-identity instruction stimulates processes that are mechanistic and occur unconsciously. These processes are to be seen as a kind of background activity that occurs in combination with other kinds of cognitive processes. In contrast, the name-identity instruction is assumed to be associated with memory processes that conduct a search in the web of information also referred to as knowledge base or long-term memory.

According to Hunt (1980), the difference between the reaction times obtained under the physical- and name-identity instructions is an important indicator of the efficiency in human information processing. This difference is considered a measure of the speed of the retrieval of long-term memory contents. It is presented on the background of Donder's (1868) "subtractive method of latency analysis to measure the time for internal mental processes such as recognition and choice" (Posner & Mitchell, 1967, p. 392). Most importantly, however, Hunt also highlights the importance of individual differences in speed of retrieval from long-term memory. It is suggested that individuals differ with regard to size, organization, and elaboration of their web of information. Hereby, the implicit assumption is made that larger size, better organization, and deeper elaboration enable better information processing. As a consequence of this notion, reaction times obtained by the Posner task should be negatively correlated with measures of cognitive ability. This notion has stimulated numerous investigations over the past three decades (e.g., Altmeyer, Schreiner, & Schweizer, 2009; Altmeyer, Schweizer, Reiss, Ren, & Schreiner, 2013; Neubauer, Riemann, Mayer, & Angleitner, 1997; Vernon & Kantor, 1986; Vernon & Jensen, 1984). It should be noted, however, that this line of reasoning, as well as the studies derived from it, only applies to the name-identity and rule-identity conditions. In contrast, the physical identity condition does not give rise to such a supposition, although there is some reason for expecting a relationship to cognitive ability for the physical identity condition (Schweizer, 2001). For example, a meta-analysis based on the data of a total of 1064 participants revealed a correlation of $r = -.27$ between the speed of retrieval from long-term memory and intelligence (Neubauer, 1995). Some years later a correlation of only -.10 was found in a substantially increased sample (Sheppard & Vernon, 2008).

A common characteristic of the past research on the Posner task is the omission of the rule-identity condition of the original version of this task (Posner & Mitchell, 1967). The reason for this neglect appears to be the undervaluation of the rule-identity condition in comparison to the two other experimental conditions. While the transition from the physical-identity to the name-identity condition seems to include a major qualitative change in the way information is processed, the transition from the name-identity to the rule-identity condition may just appear as a mere increase of elaboration. However, even if this assumption was correct, it ignores the functional value of the rule-identity condition. Elaboration as an intensified integration of information into the web of information elicited by the rule-identity condition may lead to enhanced individual differences so that research on individual differences may especially benefit from this condition. Furthermore, the conceptualization of the transition from the physical-identity to the name-identity condition as a major change of the quality of the way information is processed can be questioned. For example, sub-processes associated with both conditions such as the comparison of information and the final decision involve the central executive of working memory (Baddeley, 1986). Moreover, the processing due to both conditions may occur partly unconsciously and automatically. Hence, both these forms of information processing may differ from each other in more or less the same way as they do from the rule-identity condition.

Another shortcoming of the past research on the Posner task is the lack of structural investigations on the data generated by this task. The Posner task yields reaction times obtained under the physical-identity, name-identity, and rule-identity conditions. Furthermore, Hunt (1980) proposes the use of the difference between the reaction times obtained with the physical-identity and the name-identity conditions. Neither this difference measure nor the three reaction times are appropriate to elucidate the potentially underlying dimensions because the identification of a latent dimension requires a minimum of three or, preferably, four indicators. The available indicators enable the identification of one underlying dimension if there is one. Therefore, it remains an open question at this point, whether one dimension is underlying all the three conditions. Alternatively, there may be two or three dimensions or even a hierarchical structure underlying the performances on the Posner task.

Moreover, it is unclear whether the reaction times obtained under the three conditions show causal relationships among each other. Such causal relationships are suggested by the general characteristics of cognitive information processing with its succession of steps as proposed by Posner and Mitchell (1967) or levels of processing as suggested by Craik and Lockhard (1972). According to these approaches to cognitive information processing the physical-identity condition stimulates the most basic processing since virtually all subprocesses involved in this stimulus processing are also part of stimulus processing under other conditions. Such common processing establishes relationships among the outcomes of the different instructions that can be interpreted as causal relationships.

Objectives

The first objective of the present study was the investigation of the structure of reaction times in the three instruction conditions of the Posner task. This required the representation of each condition by several indicators. The second objective was the consideration of the largely ignored rule-identity condition in the original version of the Posner task. The third objective was the investigation of the dependencies among the mental activities stimulated by the three experimental conditions. It was considered especially useful to learn about how the rule-identify condition would be related to the physical-identity and name-identity conditions.

Method

Participants

There were 58 male and 127 female student volunteers ranging in age from 18 to 49 years (mean age ± SD: 23.7 ± 5.2 years). For taking part in the present study, they received a financial reward or course credit.

Instruments

A Posner task based on the description provided by Posner et al. (1969) and Posner and Mitchell (1967) was applied in the present study. Stimulus presentation and recording of participants' responses were computer-controlled using E-Prime software. Lower and upper case letters served as stimuli. Pairs of letters were presented to the participants. They appeared in the centre of the computer screen in the beginning of each trial and remained on screen until the participants' pressed one of the two response keys.

In the physical-identity condition, participants were instructed to decide whether the two letters were physically the same (e.g. 'A A'). In the name-identity condition, they had to decide whether the two letters were semantically the same (e.g. 'A a'). In the rule-identity condition, the participants' task was to find out whether the letters belonged to the same category of letters (i.e., to decide whether both letters were vowels or consonants). In each condition, participants had to respond by pressing one of two designated keys labelled "same" and "different", respectively. The instructions emphasized to perform as accurately as possible and, at the same time, as quickly as possible.

The experimental trials were preceded by 10 practice trials. Each participant was given a total of 60 trials. The trials were evenly distributed over the three conditions by being arranged in 6 blocks (two blocks for each condition) of 10 trials each. The response time and accuracy of each response were automatically recorded.

The first two trials of each condition were excluded from data analysis because they were expected to show a low degree of reliability resulting in 18 trials for each condition. Then, for each instruction condition, three response-time and three accuracy scores were computed by averaging across six trials. In order to avoid a possible sequence effect, the first score was computed by averaging the first, seventh, thirteenth, and so on, observations of the same condition. The second score was achieved by averaging the second, eighth, fourteenth, and so on, observations of the same condition. The same procedure served the computation of the other scores. As ten participants showed excessively large reaction times in at least one of the three conditions, their data were eliminated from the dataset.

Models

Several confirmatory factor models were considered in investigating the covariances of the nine scores. The first model comprised one latent variable (i.e., factor) and nine manifest variables, while the reaction time scores served as manifest variables. All manifest variables loaded on the latent variable. The variance of the latent variable was set equal to one while the factor loadings were free for estimation. This model was denoted as *one-factor model*. The second model included three latent variables besides the nine manifest variables. Manifest variables associated with reaction times originating from the same condition loaded on the same latent variable. There were no cross-loadings and the latent variables were not allowed to correlate among each other. This model was denoted as *three-factors model*. In order to find out whether there was also a general factor underlying the first-order factors, the third model included one second-order factor besides the three first-order factors. In this model, denoted as *hierarchical model*, the first-order factors loaded on the second-order factor. Details regarding the formal aspects of the hierarchical model can be found in Schweizer, Moosbrugger and Schermelleh-Engel (2003).

Furthermore, confirmatory factor models were designed for investigating causal effects underlying the relationships among the first-order latent variables. These models differed according to the assumed effects among the first-order latent variables. In a step-wise procedure the model providing the best account of the data was determined. All these models combined the structure of the three-factors model and one or several additional links between the first-order latent variables for representing assumed causal effects. In all cases, the physical-identity latent variable provided the outset of effects as in the considered approaches (e.g., Craik & Lockhard, 1972; Posner & Mitchell, 1967) the identification of physical identity represents the first step or level of information processing. First, there was a model including an additional link from the physical-identity latent variable to the name-identity latent variable. It was denoted as *physical-name identity model*. The second model comprised a link from the physical-identity latent variable to the rule-identity latent variable. The denotation of this model was *physical-rule identity model*. Furthermore, there were two models containing two links. The *physical-name identity/physical-rule identity model* comprised the link from the physical-identity latent variable to the name-identity latent variable and the link from physical-identity latent variable to the rule-identity latent variable. A succession of links characterized the *physical-name-rule identity model*: there was a link from the physical-identity latent variable to the name-identity latent variable and another one from the name-identity latent variable to the rule-identity latent variable. Furthermore, one could assume that the rule-identity latent variable, representing the deepest level in cognitive information processing, might receive links from different sources. The corresponding model, therefore, included links according to the physical-name-rule identity model plus a link from the physical-identity latent variable to the rule-identity latent variable. This model was denoted as *complete model*.

Statistical investigation

The appropriateness of the models with respect to the data was investigated by means of the statistic software LISREL (Jöreskog & Sörbom, 2006). The evaluation of the fit statistics was conducted by using criteria recommended by Hu and Bentler (1999) and Kline (2005): normed χ^2 (=χ^2/df) ≤ 2, RMSEA ≤ .06, SRMR ≤ .08, CFI ≥ .95, NNFI ≥ .95 and GFI ≥ .90. Furthermore, comparisons of non-nested models were performed on the basis of AIC and CFI. A CFI difference of .01 and larger was assumed to indicate a substantial difference (Cheung & Rensvold, 2002).

Results

The mean reaction times varied between 724 and 1159 msec. Figure 1 provides an illustration of the course of the mean reaction times and the corresponding standard deviations.

The comparison of the mean reaction times by means of repeated-measures ANOVA revealed a significant difference ($F(2, 418)=246.0$, $p<.05$). The individual conditions were additionally compared by contrasts. There were significant differences between the physical and name identity conditions ($F(1, 209)=283.1$, $p<.05$) and the name and rule identity conditions ($F(1, 209)=245.0$, $p<.05$). The mean reaction time reflecting processing due to the name identity condition was longer than the mean reaction time reflecting processing due to the physical identity condition, and the mean reaction time reflecting processing due to the rule identity condition surmounted the mean reaction time reflecting processing due to the name identity condition.

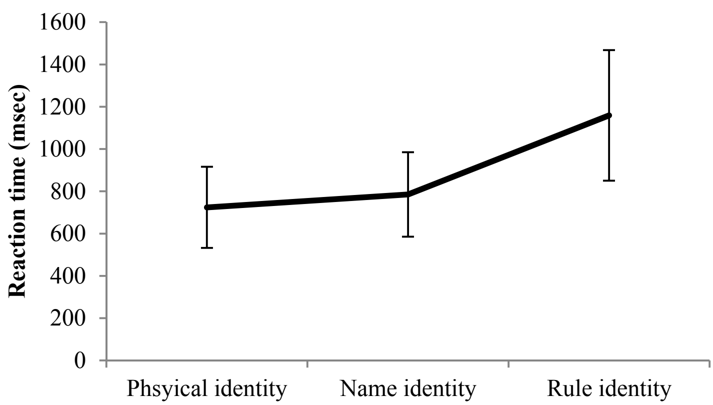

Figure 1:
Mean reaction times (and standard deviations) observed for the physical, name and rule identity conditions

The mean percentages of correct responses were 94.6, 95.1, and 89.7 for the physical-identity, name-identity, and rule-identity conditions, respectively. Although the differences between the conditions were small, repeated-measures analysis of variance (ANOVA) did not signify equality but difference, $F(2, 418)=34.5$, $p<.05$. The further investigation by means of contrasts revealed that the physical- and name-identity conditions did not differ from each other, $F(1, 209)=0.54$, n.s., but both differed significantly from the rule-identity condition, $F(1, 209)=39.8$, $p<.05$ and $F(1, 209)=51.9$, $p<.05$, respectively.

Results of the structural investigation

The one-factor model showed a bad model fit: $\chi^2(27)= 346.7$, normed $\chi^2= 12.8$, RMSEA=0.245(CI: .23, .28), SRMR=0.254, CFI=0.84, TLI=0.78, GFI=0.70. The three-factor model with uncorrelated factors showed some improvement in model fit although the fit statistics were still far from indicating good model fit: $\chi^2(27)= 205.6$, normed $\chi^2=$ 7.6, RMSEA=0.190(CI: .16, .21), SRMR=0.246, CFI=0.89, TLI=0.85, GFI=0.80. In contrast, a good degree of model fit characterized the hierarchical model: $\chi^2(24)= 35.7$, normed $\chi^2= 1.5$, RMSEA=0.052(CI: .0, .08), SRMR=0.041, CFI=0.99, TLI=0.99, GFI=0.96.

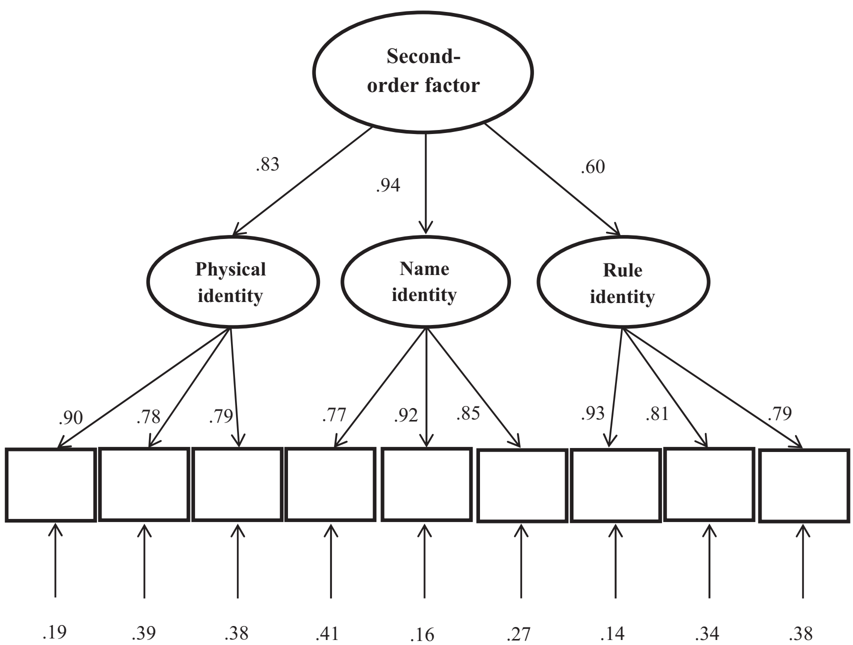

Figure 2:
Illustration of the hierarchical structure with completely standardized parameter estimates

Figure 2 provides an illustration of this hierarchical model. This Figure also includes the completely standardized parameter estimates. The estimates of the factor loadings on the second-order latent variable varied between .60 and .94 and on the first-order latent variable between .77 and .93. All of them reached the level of significance. These numbers signified that the second-order latent variable considerably contributed to all three first-order latent variables, and that the first-order latent variables were represented well by the corresponding reaction times.

Results of the investigation of causal effects

This section reports the results of the investigation of the relationships between the three latent variables in order to identify the pattern of causal effects that characterize information processing stimulated by the Posner task.

The results are presented in Table 1. The first row of this Table includes the results for the three-factor model that provided the outset for the investigation of causal effects since no effect was specified in this model. This model showed a bad model fit. The second and third rows comprised the results of models that assumed one effect originating from the physical identity latent variable. The model presented in the second row that assumed an effect from the physical identity latent variable on the name identity latent variable showed the larger improvement in model fit. The fourth and fifth rows contain

Table 1:
Fit Results Observed in Investigating Possible Causal Relationships Among the First-order Latent Variables

Model								
χ^2	df	Normed χ^2	RMSEA(90%CI)	SRMR	CFI	NNFI	GFI	AIC
No relationships								
205.6	27	7.6	0.190(.16, .21)	0.346	0.89	0.85	0.80	241.6
Physical → Name identity								
84.5	26	3.3	0.111(.08, .13)	0.240	0.96	0.94	0.91	122.5
Physical → Rule identity								
127.4	26	4.9	0.146(.12, .17)	0.311	0.91	0.88	0.87	165.4
Physical → Name identity, Physical → Rule identity								
44.8	25	1.8	0.066(.03, .10)	0.062	0.99	0.98	0.95	84.8
Physical → Name → Rule identity								
38.0	25	1.5	0.053(.01, .09)	0.041	0.99	0.99	0.96	80.0
Complete (Physical → Name → Rule identity, Physical → Rule identity)								
35.7	24	1.5	0.052(.00, .09)	0.041	0.99	0.99	0.96	77.7

the results of models assuming two effects. The model with links from physical- to name-identity and from name- to rule-identity led to a good model fit. The lower AIC revealed that this model described the data better than the other model with two links (from physical to name identity and from physical to rule identity). Finally, the model that considered all three possible effects (*complete model*) showed the overall best degree of model fit according to AIC.

Although the best model fit was observed for the complete model, it could not be accepted as the best model for representing the overall system of causal effects since the path coefficient of the link from the physical identity latent variable on the rule identity latent variable did not reach the level of significance ($\beta = .15$, $t = 1.14$, n.s.). Eliminating this effect from the complete model transformed it back into the model characterized by the links from the physical to name identity latent variables and from the name to rule identity latent variables. The remaining path coefficients linking the physical identity latent variable to the name identity latent variable and from the name identity latent variable to the rule identity latent variable reached the level of significance ($\beta = .79$, $t = 9.7$, $p<.05$ and $\beta = .58$, $t = 7.3$, $p<.05$ in corresponding order).

Based on the results presented so far the question remained whether the name identity latent variable only served as a mediator between the physical and rule identity latent variables or whether this latent variable additionally contributed to the prediction of the rule identity latent variable. In order to answer this question, the contribution of the physical identity latent variable was eliminated from the correlation between the other latent variables. The remaining partial correlation was .33 ($p<.05$) suggesting that there was also a unique contribution of the name identity latent variable.

Discussion

The investigation of the structure on the basis of subscores revealed that the mental information processing stimulated by the three conditions is in line with a hierarchical structure. The finding of a second-order factor represents the commonality of reaction times in the three conditions. Some sources of commonality are obvious, such as the type of stimuli, the way stimulus information is acquired and the activities following the final decision. The contributions of other potential sources of commonality, such as properties of mental information processing and the organization of the web of information are not clear. So some commonality may simply be due to auxiliary processing necessary for completing the task (Schweizer, 2007).

Furthermore, the study reported in this paper reveals the rule-identity condition, a basic part of the original Posner task (Posner & Mitchell, 1967) but omitted from the subsequent research work, as a source of additional information regarding the speed of the retrieval of long-term memory contents. The reaction time stimulated by the rule-identity condition clearly differs from the reaction times stimulated by the other conditions. The additional time necessary for checking the rule-identity characterizes this condition as the most demanding one. Furthermore, according to the results of the structural investigation the processing stimulated by the rule-identity condition shares common variance with the processing due to the other conditions but there is also unique variance. The unique variance clearly shows that processing due to the rule-identity condition is more than just a kind of intensified processing due to the name-identity condition. However, what it actually represents cannot be determined within the limitations of the present study. Further research is necessary for achieving clarification.

Moreover, the investigation of the causal effects led to a result that underlines the special status of the rule-identity condition. In this investigation the focus was on the model-data fit whereat different models assume different links relating the latent variables to each other. In these models the physical-identity latent variable always takes the role of the outset latent variable whereas the roles of the other latent variables change. Cognitive information processing theory justifies the special role of the physical-identity latent variable. The comparisons of models reveal that the name-identity latent variable exerts an effect on the rule-identity latent variable in two ways. First, it (partially) mediates the effect of the physical-identity latent variable on the rule-identity latent variable and, secondly, it exerts an effect on the rule-identity latent variable irrespective of the physical-identity latent variable.

Finally, the possible speed-accuracy trade-off needs to be addressed. Besides reaction times, also accuracy varied with the conditions. Accuracy was higher in the physical- and name-identity conditions compared to the rule-identity condition. This could mean a speed-accuracy trade-off in the sense that the reaction times in the rule-identity condition were lower than otherwise since the participants didn't spend enough time to reach the accuracy level as in the other conditions. The comparison of the reaction times, however, revealed that the reaction times in the rule-identity condition considerably surmounted the other reaction times. Thus, it is unlikely that the decreased accuracy in the rule-identity condition was caused by a quick and more superficial processing as it would be the case for the classical speed-accuracy trade-off. Instead, the rule-identity condition seems to be more challenging and requiring a deeper processing compared to the physical- and name-identity conditions. This led to lower mean accuracy but also to still longer reaction times.

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