Studia Psychologiczne, t. 49 (2011), z. 4, s. 41 – 53
PL ISSN 0081–685X
DOI: 10.2478/v10167-010-0039-3

Jarosław Orzechowski and Edward Nęcka

Jagiellonian University
Warsaw School of Social Sciences and Humanities

INTELLIGENCE AND PARALLEL VERSUS SEQUENTIAL ORGANIZATION OF INFORMATION PROCESSING IN ANALOGICAL REASONING

The construct of the organization of information processing (OIP) has been adopted as a possible cognitive mechanism responsible for human intelligent functioning. Participants (N = 77) were asked to solve an analogical reasoning task, a test of divided attention, a working memory capacity test, and Raven's Advanced Progressive Matrices as a standard test of general fluid intelligence. On the basis of the chronometric analysis of their performance in the analogy task, participants were divided into those preferring to use parallel or sequential modes of organization of information processing. It appeared that intelligent people using the parallel mode of processing obtained the best results in the analogical reasoning test. Other subgroups did not differ substantially from one another. It also appeared that intelligent people using the parallel mode of processing performed equally well regardless of their attentional resources and working memory capacity, whereas people using the sequential mode of processing were much more dependent on these basic cognitive limitations. A compensatory mechanism is suggested in order to account for this data: the parallel mode of processing probably helps to compensate for deficient attention or impaired working memory, whereas the sequential mode cannot act in a compensatory way.

Keywords: intelligence, analogical reasoning, parallel processing, sequential processing, attention, working memory

This paper explores the role of parallel versus sequential information processing in dealing with analogical problem solving tasks by more and less intelligent persons. Compound interactions between parallel versus sequential processing, cognitive resources of attention and working memory, and fluid intelligence will be examined in order to establish the conditions in which an individual is best predisposed to deal with analogy tasks. We will attempt to demonstrate that parallel (rather than sequential) processing makes a person less vulnerable to the detrimental consequences of ineffective attention or impaired working memory, provided that high levels of psychometric intelligence are nonetheless observed. The data allows for speculation about possible sources and mechanisms of individual differences in efficiency of analogical reasoning.

Intelligence is frequently defined as an ability to solve complex problems (Sternberg & Detterman, 1986). According to Carlstedt, Gustafsson and Ullstadius (2000), who comment on the results of the survey conducted by Linda Gottfredson (1997), two aspects of human intelligence appear essential: quick adaptation to new situations and efficient solution of complex cognitive tasks. Hence, in order to assess who is intelligent, it is necessary to work out the criteria based on either novelty or complexity. In practice, the complexity criterion is more frequently applied (at least in measurement) due to the fact that novel tasks and situations are difficult to arrange in controlled conditions of psychological assessment. Intelligence tests are thus typically constructed as sets of tasks that require solution of a series of complex problems, usually inductive reasoning problems such as analogy, series completion, and classifications (Lohman, 2000; Sternberg, 1985).

Although complex cognitive tasks are widely used in the assessment of intelligence, they are less popular in psychological investigations of the cognitive processes underlying intelligent performance (Nęcka & Orzechowski, 2005; Orzechowski, 2010). Sternberg's (1977a, 1977b, 1985) influential work on componential analysis is a widely cited but not quite often pursued example of how analogical reasoning tasks may be used in order to decompose the cognitive processes responsible for intelligence. Other important examples are investigations of the process of solving certain intelligence tests (Hunt, 1974). For instance, Carpenter, Just, and Shell (1990) found two sources of individual differences in performance on Raven's test: the ability to infer multiple relations between objects and the ability to divide complex test items into simpler subgoals. This kind of approach is generally not very popular among researchers, probably due to the fact that complex problem solving does not allow for straightforward insight into the very core of human intelligent functioning. Even though intelligence manifests itself in complex problem solving, it is not easily observable through such tasks. Efforts to understand intelligence in this manner resemble making inferences about the construction and mechanisms of a toasting machine only on the basis of a piece of toast's taste. There is of course a connection between taste and the functioning of the machine, but taste can tell us little about the mechanisms underlying the process of toasting.

Therefore, an alternative approach, consisting of the study of elementary cognitive processes which underlie intelligence, has been adopted (Deary, 2000). Studies on reaction time (Jensen, 1982, 1987), inspection time (Deary, 1993; Nettelbeck, 1987), attention (Nęcka, 1996; Schweizer, 2010; Stankov, 1983; Sullivan & Stankov, 1990), and working memory (Chuderski and Nęcka, 2011; Kyllonen & Christal, 1990; Nęcka, 1992) brought about an abundance of data concerning the relationships between psychometric intelligence and elementary cognitive tasks (ECTs). These data are usually interpreted in terms of the bottom-up explanation of intelligence: since ECTs are simple enough to be tackled with no demands on intelligence, their connections with IQ suggest that there exist certain basic information processing foundations for higher mental capacities. While adopting the top-down approach, it is always tempting to say that some people do better with complex tasks because they are intelligent, whereas the bottom-up approach suggests that some people are intelligent because they are fast or accurate in various ECTs. Assuming that the more elementary functions determine more complex ones, the bottom-up approach allows for speculation regarding the nature of intelligence instead of treating it as an explanatory factor.

In this paper, we employ a mode of studying human intelligence that needs both top-down and bottom-up approaches (Nęcka & Orzechowski, 2005; Orzechowski, 2010). We focus on analogical reasoning as one of the prototypical intellectual processes which take place in numerous test-like and real-life tasks. It is widely accepted that analogy and relational reasoning must be treated as two of the most important constituents of human intelligence (Holyoak, 2005). However, we do not aim at the Sternberg-like decomposition of successive stages of analogy solution (Sternberg, 1977a, 1977b). We intend to use the analogy tasks as a means to activate the human information processing apparatus and to inspect whether it works in the parallel or sequential mode. For that goal, we suggest to use the term "organization of information processing" (OIP), introduced by Orzechowski (1998, 2004) in his non-linear parallel model of analogical reasoning. OIP refers to the individually differentiated modes of information processing, related to the sequential-parallel dimension. In the case of sequential OIP, each component of the cognitive process is initiated only after termination of the previous one. In the case of parallel processing, consecutive components are "switched on" as early as possible, usually before the termination of previous process (see: Logan, 2002; Van Zandt & Townsend, 1993). Pure sequential and parallel modes of processing are assumed to constitute opposite poles of the continuous dimension of OIP. Real mental processes locate themselves somewhere in the middle of this dimension (McClelland, 1979).

According to the model, modes of OIP differ in speed of processing as well as in the demands they put on the cognitive system. Parallel OIP reduces the time needed to complete a task because consecutive stages overlap in time, thus cutting down the overall response latency. Due to the necessity to control two or more components simultaneously, this kind of OIP calls for the investment of more attentional resources. Storage capacity of working memory (WMC), on the other hand, is less exploited in parallel processing since all necessary information is easily available in perception. On the other hand, in the case of sequential OIP mental tasks are completed slower because there is no time reduction due to partial overlap of consecutive stages of processing. As to mental resources demands, the sequential OIP needs more storage capacity but less attentional resources. Sequential processing is not possible without keeping information about the previous stage in the WM. However, attentional resources are not substantially exhausted due to the fact that the pieces of task information are dispersed among successive stages of processing. Thus, parallel OIP should need a greater amount of attentional resources and less WMC, whereas sequential OIP should require the opposite (i.e. capacious WM rather than large amount of attentional resources). In other words, parallel OIP is more demanding for attention than for WM, whereas sequential OIP is more demanding for WM than for attention.

The relationships between mental resources and OIP are assumed to be mutual. Certain modes of OIP require more attention and less storage capacity, or vice versa. For instance, a person using the sequential mode of processing must clean out their storage capacity of WM from unnecessary or unwanted chunks of information, whereas a person who wishes to process information in the parallel mode should mobilize their attentional mechanisms and shed the surplus of information that usually resides in its focus. By doing so, cognitive resources can be prepared to meet requirements set by certain modes of OIP. However, sequential or parallel OIP can also be switched on or off in order to compensate for scarcity of mental resources. Attention and working memory are limited in their capacity to deal with complex situations. If capacities are at the highest possible level and thus cannot be further mobilized, there may be an opportunity to change the OIP in order to release some amount of mental resources. In this way, mental resources may be mobilized in order to enable the preferred mode of OIP, whereas certain modes of OIP may compensate for the insufficient amount of mental resources.

Taking into account the above-mentioned theoretical premises, we hypothesize that psychometric intelligence should interact with the organization of information processing in determining the level of performance on an analogical reasoning task. This is consistent with the hypothesis formulated by Raz, Willerman, and Yama (1987), according to which efficiency in parallel processing tasks should correlate with IQ while in serial processing tasks such a correlation should not occur. We predict that high intelligence individuals are generally more accurate than those with low intelligence, particularly so if they prefer the parallel mode of processing. In other words, being an intelligent person with preferences for the parallel mode of cognitive processing should result in the best indices of performance on analogy tasks. Although high intelligence individuals can "afford" parallel OIP thanks to their efficient attention (Dempster & Corkill, 1999; Hunt & Lansman, 1982; Nęcka, 1996; Schweizer & Moosbrugger, 2003) and sequential OIP thanks to their capacious working memory (Ackerman, Beier, and Boyle, 2005; Chuderski, Taraday, Necka, & Smoleń, 2012; Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Kyllonen & Christal, 1990; Miller & Vernon, 1992; Nęcka, 1992; Süß, Oberauer, Wittmann, Wilhelm, & Schulze, 2002), we assume that they prefer the more profitable parallel mode. Of course, they do not have to prefer this mode of processing, in which case they should obtain slightly worse indices of performance compared to their "parallel" peers. It should be so because the sequential mode of processing, if preferred, makes a person more prone to errors in the analogy tasks. Sequential OIP is more demanding in terms of temporary storage capacity, thus increasing the probability of error. Low intelligence individuals would likely be characterized by large number of errors, regardless of their preferred OIP.

METHOD

Participants

Seventy-seven high school students, 38 male and 39 female, took part in this experiment. Their average age was 17.6 years (*SD* = 0.6). Each participant was paid a small amount of money at the end of the experimental procedure. Participation in this research was voluntary. However, as participants were juvenile, we additionally asked for parental consent.

Analogical Reasoning Task (ART)

The task consisted of 30 non-verbal analogies, created according to the scheme A:B::C:D (Orzechowski, 1998). In every trial, a computer generated a set of geometrical figures and the rule of their transformation. Part B of every analogy task was constructed as a transformation of part A, according to one of the three rules of alteration: by 180-degree rotation, by mirror vertical reflection, and by mirror horizontal reflection. Part C was generated independently of parts A and B, and part D had to be chosen from among three alternatives located at the bottom of the screen (see Figure 1). Participants were asked to choose the correct answer, on the condition that the relation C:D is similar to the relation A: B. The algorithm of analogy generation ensured a low probability of identical sets of stimuli to appear in any pair of consecutive trials, while the principle of comparable levels of complexity of all trials was applied. The instructions and five practice trials preceded the task proper.

There were three experimental conditions, 10 trials per condition. The task was divided into two parts: single (first condition) and dual (second and third conditions). In the single condition, appearance of each part of the task required pressing a

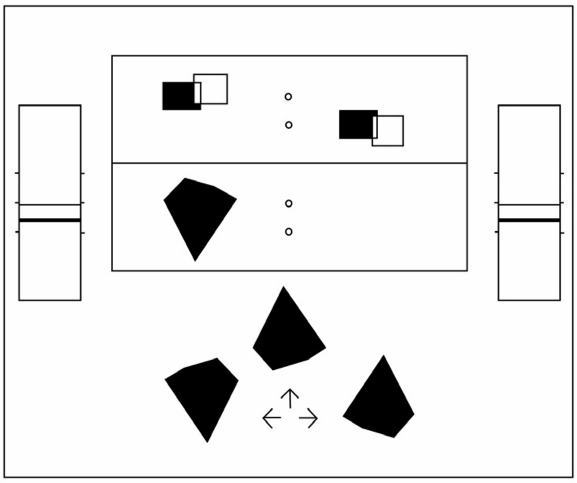

Figure 1. Analogical Reasoning Test (ART): an exemplary item.

computer key (down arrow). Thus, participants could control the presentation time of consecutive task elements (A, B, C while the experimenters were able to measure the exploration time of each part of the analogy task, as well as the overall decision-making time (A, B, C, D).

In the second and third conditions, a dual task paradigm was employed. Simultaneously with the analogical reasoning task, participants had to execute a simple psychomotor task: they were required to keep a constantly moving line in one position on the computer screen. They were instructed that the analogy task was the priority, with the level of secondary task execution being an index of the participants' attentional engagement in the primary task. The more resources left over while processing the priority task, the better performance on the secondary task should be. The second condition was termed "voluntary", as each person was free to choose the tempo of switching on consecutive parts of the task. As a result, the participant was also free to choose the preferred OIP and cognitive strategy.

In the third condition, participants also controlled the screening of consecutive parts of the analogy task but presentation of each part automatically removed the previous one from the screen. For example, appearance of part B of the analogy task caused that part A disappeared from the screen. So, in the third condition, only one part of the task was visible. This condition was therefore labeled "forced". In contrast to the previously described "voluntary" condition, this one called for analytical and sequential processing of information as successive parts of the analogy task had to be processed one by one in order to assure the appropriate amount of information needed for proceeding stages of processing. In cases of insufficient, careless, or superficial processing, an error could appear simply because additional exploration of previous parts of the analogy was impossible. In other words, the analysis of incoming material had to occur immediately and with sufficient accuracy.

The difference in reaction times (RT) between "forced" and "voluntary" conditions served as an index of the OIP mode during the analogical reasoning process. We assumed that people having higher efficiency in, or preference for, the parallel mode of processing would lose more if forced to process information in a serial manner connected to the sequential OIP. In other words, the RT difference between "forced" and "voluntary" conditions should be greater for subjects preferring parallel processing. Conversely, the loss caused by sequential processing enforcement should be quite small for sequential OIP participants because the task requirements would be compatible with their natural preferences, thus resulting in increased efficiency of task performance. Our sample of participants was dichotomized according to the median point of the OIP distribution so that further analyses could be performed within the ANOVA model.

RT was measured during the entire ART task (3 conditions x 4 parts of analogy = 12 measures), together with the number of errors in analogies (3 measures) and number of errors in the secondary task for dual task conditions (2 conditions x 4 parts = 8 measures). Average time needed to complete this task was 30 minutes.

Divided Attention Test (DiVA)

This procedure, developed by Nęcka and colleagues (Nęcka, 1996; see also: Nęcka, 2000), is an integrated attention test enabling the measurement of efficiency of selective and divided attention. Its development was based on the dual task paradigm (Kahneman, 1973). Stimuli were letters appearing within two boxes on the computer screen. In the central box, a capital letter was presented as a target. Participants had to respond with the left mouse key every time a small letter, identical in meaning with the target, appeared on the screen. The target changed after each 20 seconds, and during this time four signals (i.e., small relevant letters) appeared. There were three to five probe letters on the screen at the same time. They appeared randomly within the biggest box (14 x 18 cm.). The letters were presented in a constant tempo: every second, one letter disappeared and a new one appeared on the screen. In half of the conditions, a distractor appeared on the screen in the form of a capital letter physically identical to the target. Subjects had to respond only to small letters corresponding to the target, so all the irrelevant small letters, as well as distractors, had to be ignored.

In the second part of the test, a simple psychomotor task was introduced. This task had to be performed together with the selection of letters and required participants to control the position of a line moving within the rectangle placed near the left or right end of the computer screen. The line was constantly descending and every few seconds changed its place from the left to the right side, or *vice versa*. Pressing the right mouse key made the line move up. If the line moved beyond the rectangle (i.e., too low or too high), the computer generated a 440 MHz sound which stopped when the participant corrected the position of the line. Thus, not pressing the key caused the line drop down, while pressing it constantly moved it too high; both cases evoked an unpleasant sound. These operations were introduced in order to make it difficult for participants to ignore the secondary task altogether, or to automatize it too quickly.

According to the dual task paradigm, the decrease of efficiency in a selection task between dual and single conditions should be lower for people with an efficient resource allocation mechanism. This advantage should reveal itself in shorter RTs and a lower number of errors. Participants were instructed that both tasks were equally important. Both parts, single and dual, were preceded with practice trials.

Horizon task

This task was developed by Nęcka and colleagues (Nęcka, 2000) as an assessment tool for the efficiency of working memory. It requires participants to remember complex non-verbal stimuli: figures built of 8 squares, of which 4 were always filled and 4 were empty. Altogether, 56 different figures of that type were used, all of similar difficulty concerning visual encoding. Each figure appeared twice in the course of the whole task, in precisely defined intervals. The Horizon task consisted of 8 experimental conditions in which the interval between the first and the second appearance of each stimulus was manipulated. These two presentations could be interspersed by one to eight other figures. Seven trials were introduced for each condition, totaling 112 trials altogether (8 conditions x 7 trials x 2 presentations of each stimulus). Conditions were randomized and blocked in a script of trials, identical for each participant. After starting the program, all 56 figures were randomly attributed to 56 slots in the script. Thus, the rigid sequence of presentations was filled with different content each time. The task was to decide whether the figure presented on screen had already been shown. The YES, NO or DON'T KNOW decisions were connected to the right, left, or up arrow on a computer keyboard respectively. After each press, another figure appeared. The total amount of correct answers was used as an index of working memory capacity. Total time necessary to complete the Horizon task ranged between 15 to 20 minutes.

Psychometric tool

We used Raven's Advanced Progressive Matrices (Raven, Court, & Raven, 1983) as an intelligence test apt to providing a good approximation of the participants' general fluid intelligence factor (*Gf*).

RESULTS

Main Effects

The average RT in the basic ART condition (single task condition) was 28.6 sec. (*SD* = 11.5

Table 1 Chronometric and accuracy measures of performance on the analogical reasoning task (ART)

Condition	Basic		Voluntary		Forced	
	RT	SD	RT	SD	RT	SD
Stage A	1.85	1.00	1.80	0.89	8.70	3.62
Stage B	2.01	2.33	1.92	2.82	6.53	4.93
Stage C	2.25	2.54	1.62	2.13	7.29	6.17
Stage D	22.96	12.06	20.31	11.57	5.09	2.52
Error rate	2.48		2.22		4.75	

Note. RT – reaction time, SD – standard deviation of reaction time, error rate – the average number of errors.

Table 2. Basic statistics for indices of organization of information processing (OIP), amount of attentional resources (AR), capacity of working memory (WMC), and general fluid intelligence (Gf).

Index	mean	SD	median
OIP (sec.)	1.85	12.15	1.08
AR (error rate)	10.39	6.76	9.00
WMC (error rate)	47.45	10.37	47.5
Gf (RAPM score)	22.42	5.68	23.00

sec.), whereas in the double task condition it was 25.6 sec. (*SD* = 11.7 sec). These conditions did not differ significantly concerning RT, which corroborates the effectiveness of the instruction to treat the analogy task as a priority in the double task condition. RT of correct answers was shorter than reaction times of incorrect answers, regardless of the condition ($F(1,59) = 31.70$; $p < 0.0001$). As to accuracy, the ART task appeared quite difficult for the participants, since they committed 9.4 errors on average in 30 trials (*SD* = 3.8). The third condition ("forced") was the most difficult: in 10 tasks 4.75 errors were committed (*SD* = 1.6). No significant difference was found between "basic" and "voluntary" conditions concerning the number of errors. Basic statistics for the analogy task performance in all three conditions are presented in Table 1. Basic statistics for remaining measures are presented in Table 2.

Experimental manipulation with the "voluntary" versus "forced" conditions led to different time courses of solving the analogy task ($F(6, 450) = 131,49$; $p = 0,0001$; see Figure 2). In the "voluntary" condition, RTs were similar to the single task condition: participants analyzed the first three parts of an analogy for about 2 seconds, and then took approximately 20 seconds to correctly choose part D. Comparison of overall RTs showed no significant differences between all three conditions. However, in the third condition ("forced") the number of errors

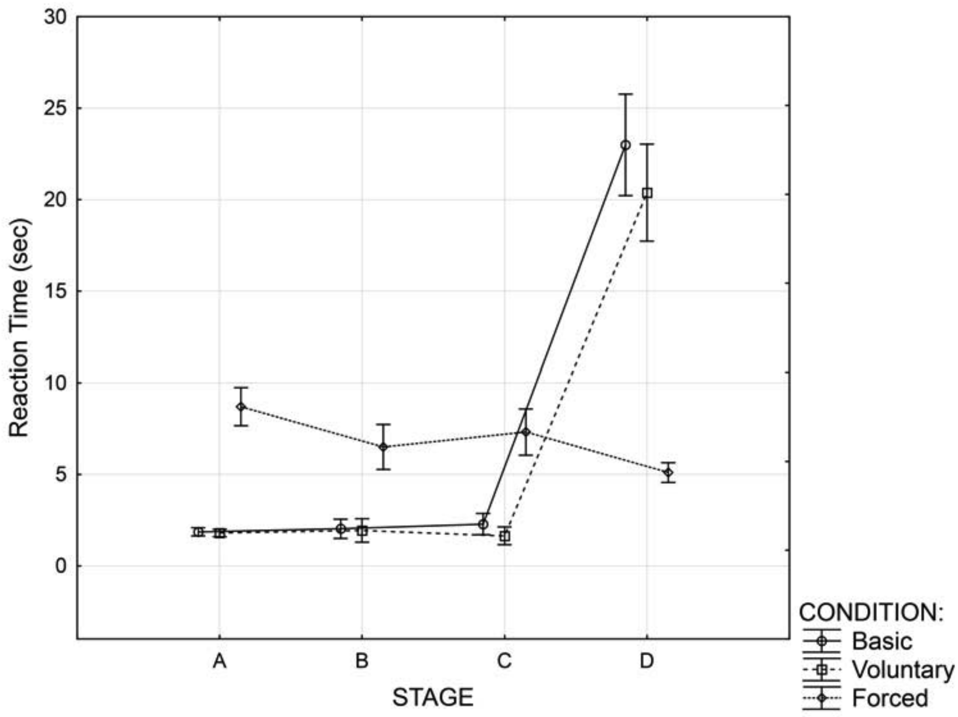

Figure 2. Reaction time of correct responses in three conditions of the ART task. Whiskers represent 95% CI.

increased significantly ($F(1,76) = 128.90$; $p < 0.0001$), and the efficiency of secondary task performance dropped substantially ($F(1,76) = 24.74$; $p < 0.0001$).

Differential Effects

Firstly, we checked whether the intelligence test results correlated with measures of working memory and attention in a pattern compatible with the results of previous studies. We found that the raw score on Raven's matrices correlated negatively and significantly with the overall number of errors committed in the DiVA ($r = -0.41$, $p < 0.001$) and Horizon ($r = -0.30$, $p < 0.05$) tasks. Although these relationships were not particularly strong, they confirmed our expectations that with increasing intelligence the results obtained on working memory and attention tests improves. We also found that intelligence, measured with RAPM, correlated negatively with the overall number of errors in the ART task ($r = -0.47$, $p < 0.01$), thus confirming the increased efficiency of intelligent people in tasks requiring relational thinking and fluid reasoning (Chuderski & Nęcka, submitted; Holyoak, 2005).

Secondly, we investigated the relationships between the OIP index, defined as the RT difference between the "forced" and "voluntary" conditions, and the analogy task performance indices. We found a negative relationship between OIP and the overall number of errors in the ART task ($r = -0.31$, $p < 0.01$). This result suggests that people preferring the parallel mode of processing showed increased accuracy in the analogical reasoning task. Closer examination of this relationship revealed that it occurred in the "forced" condition only; in the "basic" and "voluntary" conditions, respective correlation coefficients were statistically nonsignificant.

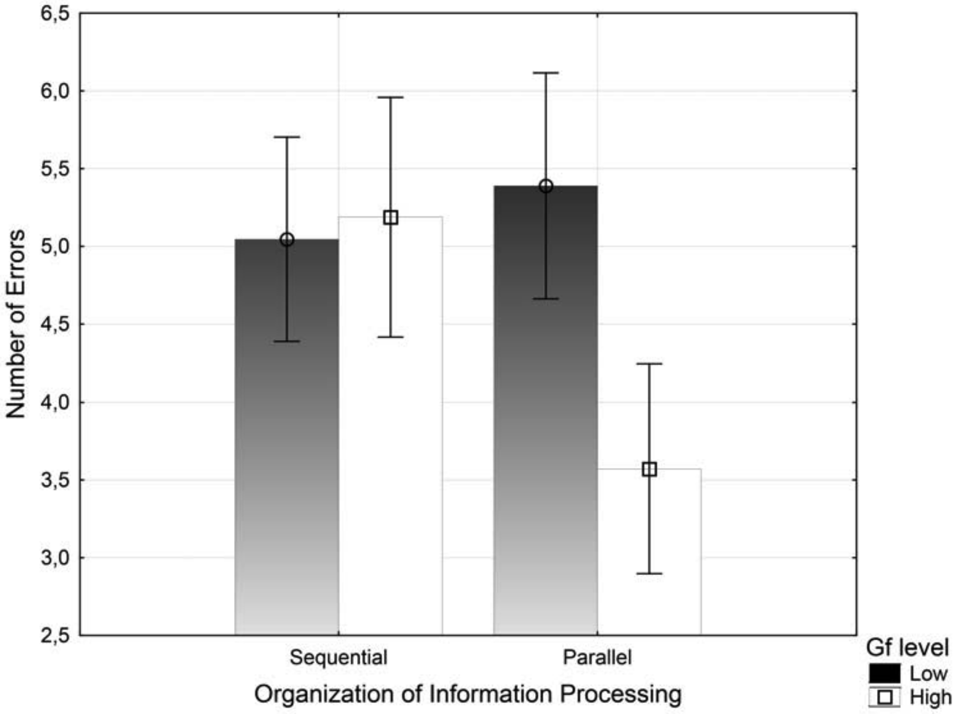

Figure 3. Average number of errors in the ART task, type of OIP, and IQ level. Whiskers represent 95% CI.

Participants using the parallel mode of OIP benefitted from "forced" sequential mode of task presentation, whereas in the case of the holistic mode of presentation ("voluntary" condition) they did not show any prevalence over their "sequential" peers.

Finally, we checked the relationships between OIP and *Gf* so that the main hypothesis of this study could be tested. We found that, although OIP did not correlate with intelligence level directly, it moderated the relationship of intelligence to reasoning efficiency as measured by the overall number of errors in the ART task. Low intelligence individuals committed significantly more errors than those with high intelligence regardless of sequential or parallel OIP use. For high intelligence individuals, the preferred mode of OIP determined relatively lower or higher number of errors committed in the ART task. As we can see (Figure 3), if the participants with high *Gf* employed parallel OIP, their results in the analogical reasoning task were much better than in the case of high *Gf* participants with sequential OIP ($F(1, 73) = 7.59$, $p<0.008$). Post hoc analysis revealed that the high *Gf*/parallel OIP subgroup significantly outperformed other subgroups shown in Figure 3 (the difference between groups 1 and 4: $p < 0.0001$, 2 and 4: $p < 0.0001$, 3 and 4: $p < 0.004$). The three remaining groups did not differ significantly in ART task accuracy.

In order to highlight the importance of OIP for the effectiveness of analogical reasoning, we performed a series of regression analyses. The proportion of variance on ART task accuracy explained by the joint influence of attentional resources and working memory capacity equaled 28.7% ($R^2 = 0.2869$, $F(4, 69) = 6.94$, $p < 0.0001$). When *Gf* (measured with Raven's matrices) entered the regression equation, this proportion increased to 41.5% ($R^2 = 0.4146$, $F(6, 66) = 7.79$, $p < 0.0001$). After adding OIP into the equation, the model was able to explain as much as 49.2% of variance ($R^2 = 0.4916$, $F(8, 64) = 7.73$, $p < 0.0001$). Thus, we were able to determine that the organization of information processing, understood as an individually differentiated preference for parallel or sequential processing, accounted for about 8% of variance of ART task accuracy. This contribution was smaller than that of attention, working memory, and intelligence, but nevertheless it appeared sufficiently important to be taken into account in the theoretical models of reasoning.

DISCUSSION

Before entering into the discussion, let us recapitulate our findings. We developed a new cognitive task that required analogical reasoning. This task had three versions, differing in the mode of presentation of successive stages of each analogy (holistic versus successive) and in the cognitive load put on participants (single versus dual task conditions). Manipulations with reaction time in this task allowed for construction of an index of the organization of information processing (OIP). The difference in reaction times between "forced" and "voluntary" conditions served as an index of OIP on the analogical reasoning task. We assumed that people who have a general preference for parallel OIP would slow down if forced to process information in a serial manner, whereas their peers with a preference for sequential OIP would not. We found that psychometric *Gf* correlated with increased accuracy in the cognitive tasks measuring attentional resources and working memory capacity. Moreover, intelligent individuals were more accurate in the analogical reasoning task and obtained lower OIP indices, which suggests that intelligence tends to co-occur with parallel rather than sequential mode of information processing. Finally, we found a regression model with four independent variables (attentional resources, working memory, organization of information processing, and intelligence) which was able to explain as much as 49.2% of variance in accuracy of analogical reasoning.

It seems, that we indirectly confirmed the hypothesis suggested by Raz, Willerman and Yama (1987), according to which efficiency in parallel processing tasks should correlate with IQ, while in serial processing tasks such a correlation should not occur. This prediction has not previously been empirically confirmed. Diascro and Brody (1993) used a visual detection task that required detection of diagonal and vertical lines (Treisman & Gromican, 1988), assuming that detection of diagonal lines works in the parallel mode, whereas detection of vertical lines needs the sequential mode. Such an effect appeared and was confirmed by the flat RT(N) function, where N represented the number of lines in the perceptual field. However, Diascro and Brody (1993) did not confirm their differential hypothesis concerning the relationship between IQ and detection time of diagonal lines. Performance on both serial and parallel processing tasks did not depend on IQ. Of course, we used different methodology and an entirely new operationalization of basic theoretical constructs. In our research, we employed complex cognitive tasks that enabled us to verify the hypothesis using accuracy level. It is worth to underscore that the relationships between intelligence and OIP were observed when accuracy indices were taken into account as dependent variables. There is nothing extraordinary in these results: IQ-RT correlation in complex cognitive tasks usually decreases with task complexity, whereas IQ-accuracy correlation increases (Wittmann & Süß, 1999).

To account for these effects, we call for a mechanism of compensation. Limitations of attention and working memory are severe and commonly observed (see: Nęcka, Orzechowski, & Szymura, 2006). Inability to mobilize the required amount of attentional resources, or a decreased capacity of working memory, cause serious deficiencies in information processing and may result in low performance on important cognitive tasks. Complex cognitive tasks seem particularly vulnerable from this point of view because of the demands they put on the human mind. Thus, a question arises whether such limitations can be compensated for, and what the best compensatory mechanisms are. Our research suggests that the parallel organization of information processing, as opposed to sequential, may serve as a compensatory factor. However, this factor seems to work only in the case of highly intelligent individuals. Obviously, the compensatory mechanism must be limited to quite a small percentage of the population because it is available only to those who are relatively intelligent, whose attention and working memory mechanisms are already highly developed. In fact, efficient attention and capacious working memory are just correlates of intelligence and they are not apt to account for all *Gf* variance. Therefore, there must be individuals whose attention or working memory does not work at the highest possible level but whose intellectual efficacy is still good enough to locate them within the relatively high levels of *Gf* distribution. The compensatory mechanism (as described above) is fully available to such people, giving them an opportunity to obtain improving measures of performance on complex cognitive tasks.

The obtained results may be discussed from yet another perspective, namely, from the intelligence research point of view. Attention and working memory are regarded as the most important cognitive prerequisites of general intelligence. Working memory capacity seems to be particularly important as a strong correlate of, or even a substitute for, general mental ability (Chuderski & Nęcka, submitted). However, research on the cognitive foundations for intelligence should not be restricted to attention and working memory as cognitive mechanisms highly limited in their efficiency. It seems that other aspects of cognition, those not involved directly in limitations and efficiency but rather pertaining to preferences, should also be considered. We propose that the organization of information processing is a good candidate for being a cognitive substrate of intelligence, and this stance is supported by the fact that OIP significantly increased the amount of explained variance when added into our regression equation. The construct of OIP refers to preferences rather than abilities but nevertheless it seems apt to account for a substantial part of variance present in general mental ability, as measured by standard intelligence tests. In other words, organization of information processing should add some unique amount of explained variance of general intelligence, thus supplementing the already recognized factors of attentional resources and working memory capacity. In order to check if this line of reasoning makes sense we need alternative methods for operationalization of the OPI construct, which should take place in further research. We also need to check if OIP adds to the percentage of explained variance when *Gf*, rather than analogical reasoning accuracy, is used as a dependent variable. But taking into account the fact that analogical reasoning is closely related to fluid intelligence (Holyoak, 2005), the proposed line of explanation seems tenable.

REFERENCES

Ackerman, P. L., Beier, M. E., & Boyle, M. O. (2005). Working memory and intelligence: The same or different constructs? *Psychological Bulletin, 131,* 30-60.

Carlstedt, B., Gustafsson, J. E., & Ullstadius, E. (2000). Item sequencing effects on the measurement of fluid intelligence. *Intelligence*, *28*, 145–160.

Carpenter, P. A., Just, M. A., & Shell, P. (1990). What one intelligence test measures: A theoretical account of the processing in the Raven Progressive Matrices test. *Psychological Review, 97,* 404-431.

Chuderski, A., & Nęcka, E. (2010). Intelligence and cognitive control. In A. Gruszka, G. Matthews, & B. Szymura (Eds.), *Handbook of individual differences in cognition* (pp. 263-282). New York: Springer.

Chuderski, A., Nęcka, E. (2011). The contribution of working memory to fluid reasoning: capacity, control, or both? (submitted).

Chuderski, A., Taraday, M., Necka, E., & Smoleń, T. (2012). Storage capacity explains fluid intelligence but executive control does not. *Intelligence*, *40*(3), 278-295.

Conway, A. R. A., Cowan, N., Bunting, M. F., Therriault, D. J., Minkoff, S. R. (2002). A latent variable analysis of working memory capacity, short-term memory capacity, processing speed, general fluid intelligence. *Intelligence, 30,* 163-183.

Deary, I. J. (1993). Inspection time and WAIS-R IQ subtypes: A confirmatory factor analysis study. *Intelligence, 17*, 223-236.

Deary, I. J. (2000). *Looking Down on Human Intelligence: From Psychometrics to the Brain*. Oxford: Oxford University Press.

Dempster, F. N., & Corkill, A. J. (1999). Individual differences in susceptibility to interference and general cognitive ability. *Acta Psychologica, 101,* 395-416.

Diascro, M. N., & Brody, N. (1993). Serial versus parallel processing in visual search tasks and IQ. *Personality and Individual Differences*, *14*, 243-245.

Gottfredson, L. S. (1997). Why g matters: The complexity of everyday life. *Intelligence, 24*, 79-132.

Holyoak, K. J. (2005). Analogy. In K. J. Holyoak, & R. G. Morrison (Eds.), *The Cambridge handbook on thinking and reasoning* (pp. 117-142). Cambridge: Cambridge University Press.

Hunt, E. (1974). Quote the Raven? Nevermore. In L. W. Gregg (Ed.), *Knowledge and cognition* (pp. 129-157). Potomac, MD: Lawrence Erlbaum.

Hunt, E., & Lansman, M. (1982). Individual differences in attention. In R. J. Sternberg (Ed.). *Advances in the Psychology of Human Intelligence* (pp. 207-254). Hillsdale, NJ: Lawrence Erlbaum Associates.

Jensen, A. R. (1982). The chronometry of intelligence. In R. J. Sternberg (Ed.), *Advances in the psychology of human intelligence* (pp. 255-310). Hillsdale, NJ: Lawrence Erlbaum Associates.

Jensen, A. R. (1987). Individual differences in the Hick paradigm. In P. A. Vernon (Ed.), *Speed of information processing and intelligence* (pp. 101-175). Norwood, NJ: Ablex Publishing Corporation.

Kahneman, D. (1973). *Attention and Effort*. Englewood Cliffs, NJ: Prentice-Hall.

Kyllonen, P. C., & Christal, R. E. (1990). Reasoning ability is (little more than) working-memory capacity? *Intelligence*, *14*, 389-433.

Lohman, D. F. (2000). Complex information processing and intelligence. In R. J. Sternberg (Ed.), *Handbook of intelligence* (pp. 285-340). Cambridge, UK: Cambridge University Press.

McClelland, J. L. (1979). On the time relations of mental processes: An examination of systems of processes in cascade. *Psychological Review, 86,* 287-330.

Nęcka, E. (1992). Cognitive analysis of intelligence: The significance of working memory processes. *Personality and individual differences*, *13*, 1031-1046.

Nęcka, E. (1996). The attentive mind: Intelligence in relation to selective attention, sustained attention, and dual task performance. *Polish Psychological Bulletin*, *27*, 3-24.

Nęcka, E. (1997). Attention, working memory and arousal: Concepts apt to account for the "process of intelligence". In G. Matthews (Ed.), *Cognitive Science Perspectives on Personality and Emotion*. Elsevier Science B.V.

Nęcka, E. (2000). *Pobudzenie intelektu: Zarys formalnej teorii inteligencji*. [The arousal of intellect: An outline of the formal theory of intelligence]. Kraków: Universitas.

Nęcka, E., & Orzechowski, J. (2005). Higher-order cognition and intelligence. In R. J. Sternberg & J. Praetz (Eds.), *Cognition and intelligence: Identifying the mechanisms of the mind* (pp. 122-141). Cambridge, UK: Cambridge University Press.

Nęcka, E., Orzechowski, J., & Szymura, B. (2006). *Psychologia poznawcza.* [Cognitive psychology]. Warszawa: PWN & Academica.

Nettelbeck, T. (1987). Inspection time and intelligence. In P. A. Vernon (Ed.), *Speed of information processing and intelligence* (pp. 295-346). Norwood, NJ: Ablex Publishing Corporation.

Orzechowski, J. (1998). Nieliniwo-równoległy model rozumowania przez analogię a różnice indywidualne w funkcjonowaniu poznawczym człowieka.[Nonlinear and parallel model of analogical reasoning and individual differences in human cognition.] Unpublished Ph.D. thesis.

Orzechowski, J. (2004). Poznawcze podłoże rozumowania przez analogię: Weryfikacja modelu nieliniowo-równoległego. [Cognitive basis of analogical reasoning: Verification of the nonlinear and parallel model of reasoning]. *Studia Psychologiczne*, *42*, 95-106.

Orzechowski, J. (2010). Working memory capacity and individual differences in higher-level cognition. In A. Gruszka, G. Matthews, & B. Szymura (Eds.), *Handbook of individual differences in cognition* (pp. 353-368). New York: Springer.

Raven, J. C., Court, J. H., & Raven, J. (1983). *Manual for Raven's Progressive Matrices and vocabulary scales* (Section 4, Advanced Progressive matrices). London: H.K. Lewis.

Raz, N., Willerman, L., & Yama, M. (1987). On sense and senses: Intelligence and auditory information processing. *Personality and Individual Differences*, *8*, 201-210.

Schweizer, K. (2010). The relationship of attention and intelligence. In A. Gruszka, G. Matthews, & B. Szymura (Eds.), *Handbook of individual differences in cognition* (pp. 247-262). New York: Springer.

Schweizer, K., & Moosbrugger, H. (2003). Attention and working memory as predictors of intelligence. *Intelligence, 32*, 329-347.

Stankov, L. (1983). Attention and intelligence. *Journal of Educational Psychology*, *75*, 471-490.

Sternberg, R. J. (1977a). *Intelligence, information processing, and analogical reasoning: The componential analysis of human abilities*. Hillsdale: Erlbaum.

Sternberg, R. J. (1977b). Component processes in analogical reasoning. *Psychological Review*, *84*, 353-375.

Sternberg, R. J. (1985). *Beyond IQ: A triarchic theory of human intelligence*. Cambridge: Cambridge University Press.

Sternberg, R. J., & Detterman, D. K. (1986). *What is intelligence?: Contemporary viewpoints on its nature and definition.* Norwood, NJ: Ablex Publishing Corporation.

Süß, H. M., Oberauer, K., Wittmann, W. W., Wilhelm, O., Schulze, R. (2002). Working memory capacity explains reasoning ability – and a little bit more. *Intelligence, 30,* 261-288.

Sullivan, L., & Stankov, L. (1990). Shadowing and target detection as a function of age: Implications for the role of processing resources in competing tasks and in general intelligence. *Australian Journal of Psychology*, *42*, 173-185.

Treisman, A.M., & Gromican, S. (1988). Feature analysis in early vision: Evidence from search asymmetries. *Psychological Review*, *95*, 15-48.

Wittmann, W. W., & Süß, H. M. (1999). Investigating the paths between working memory, intelligence, knowledge, and complex problem-solving performances via Brunswik symmetry. In P. L. Ackerman & R. D. Roberts (Eds.), *Learning and individual differences. Process, trait content determinants* (pp. 77–104). Washington: APA.