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RESEARCH ARTICLE OPEN ACCESS

Problem-solving As Concurrent Processing in a Network of Neural-like Elements

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Abstract:

Background: Problem-solving is considered a sequential process, when one thought is a prerequisite for the next one. However, most mental processes are parallel. Based on ideas that thinking can be considered processing information in a network of neuron-like elements functioning concurrently, we hypothesized concurrent processing always occurs in problem-solving. We suggest there are individual differences regarding the easiness of the emergence of task-related but supplementary thoughts that can be applied to elucidate how concurrent processing influences problem-solving.

Methods: A questionnaire on the emergence of supplementary thoughts was designed. It was hypothesized there may be positive correlation coefficients between scores on the questionnaire and scores on problem-solving tasks and the times taken to perform these tasks. Four tasks were used to characterize problem-solving. To study the relationship between concurrent processing and processing speed the simple reaction time task was used.

Results: Cronbach's alpha for the questionnaire was 0.705. Eight of ten correlation coefficients between scores on the questionnaire and the variables derived from the problem-solving tasks were significant. A partial correlation between scores on the questionnaire and reaction times was insignificant. There was a positive correlation between scores on the questionnaire and age. Thus, unlike other characteristics associated with flexibility in thinking, concurrent processing is not deteriorated with age.

Conclusion: Our results demonstrate concurrent processing exists and influences problem-solving. Concurrent processing and processing speed are based on distinctive mechanisms. An explanation for the fact that concurrent processing is not worsened with age is suggested.

Keywords: Thinking, Parallelism, Concurrent processing, Network, Neuron-like element, Cronbach's alpha, Problem solving.

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1. INTRODUCTION

Though solving a problem is a covert process, this process seems to be identical to all humans. There is an initial representation of the problem situation that is replaced by another representation through a series of some operations. This new representation, in turn, is replaced by the next representation owing to new operations. This process continues until one of these representations matches the goal-state that means the problem is solved. Thus, the process of solving a problem is usually considered serial, when each intermediate representation is a prerequisite for the next one.

It is important to note that mental processes, as a rule, occur concurrently. Perception is an obvious example of this because human beings can see and hear at the same time. Pain, emotions, desires occur independently of the perception of objects in the surrounding world and of each other. In these cases, mental processes are carried out concurrently, since these processes are based on different systems that can function independently. A question raises about the possibility of concurrent processes within one system that consists of similar, but not identical elements.

This question is of interest because some modern models of thinking describe solving a problem as the result of information processing in a network, which consists of similar elements that imitate the functioning of neurons in the brain [1, 2]. Information processing by such elements is carried out in parallel. In accordance with such models, the result of such a process is the achievement of a certain state by elements of the network, which is manifested in the awareness of a representation or action. These models are often used to simulate various characteristics of thinking [3-5]. It is reasonable to assume that the models based on the use of a network of neuron-like elements do not reflect cognitive processes in its entirety, but these models are useful because they can become a heuristic basis for new approaches to thinking.

Similarly to the brain, each element in a network of neuron-like elements can be connected with several others, but not with all elements in the network. This means that information is processed by different elements concurrently but in different ways. With this method of processing, it is logical to assume there may be situations when the result of the activity of one group of elements reaches a threshold of awareness, and after this the result of the activity of another group achieves the threshold independently (Fig. 1). This can be experienced as the sudden appearance of a new idea being related to the current process of thinking but markedly different from the thought that was previously in the focus of consciousness.

If concurrent processing is a real phenomenon, then its investigation, obviously, is a difficult problem, since the mechanism of concurrent processing is unconscious and beyond deliberate control. It can be assumed, however, that similarly to other cognitive processes, there are individual differences in the generation of concurrent

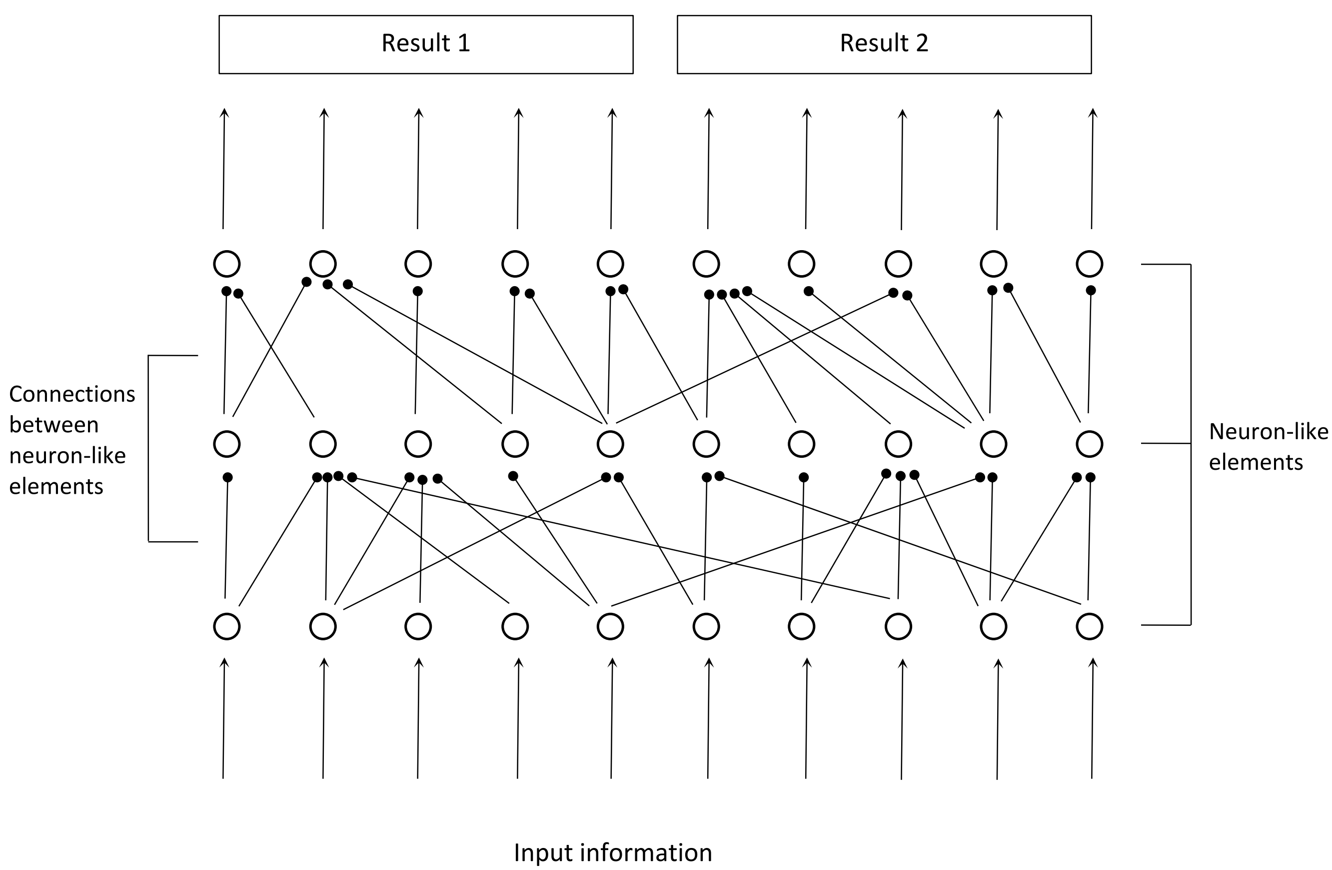

Fig. (1). Processing information by a network in which each element is connected with a limited number of other elements.

processes. In other words, unexpected, but related to solving a specific problem, ideas may come to the mind of some individuals more often than to the mind of other individuals. If to design a questionnaire including statements that describe situations in which unexpected but task-related ideas come to mind and to ask the person to scale the frequency of occurrence of such situations, then the resulting score may reflect the person's ability to generate concurrent processes.

A suggestion that the mind of some people functions in a more concurrent mode implies that their mind may generate more ideas regarding a problem and these ideas may be more diverse. At the level of consciousness this means that such individuals acknowledge ideas regarding a problem easier and more often hence they may solve the problem correctly but slowly. Therefore, it can be suggested that there may be positive correlation coefficients between scores on the questionnaire and scores on tasks being used in studies on problem-solving and the times taken to perform these tasks. One aim of our study was to explore such correlations.

There are several theories that hypothesize that concurrent processes occur in thinking, such as dual processes theories [6] or the theory of unconscious thought [7]. To the best of our knowledge, all of such theories associate concurrent processes with the existence of, at least, two systems that can function concurrently because have different architectures. Therefore, the authors of such theories study qualitative differences between responses of participants in experiments. We posit that concurrent processes emerge within one system, and hence we investigate individual differences in the quantitative characteristics of responses.

If concurrent processing influences problem-solving, then there is an important question regarding its connection with other mechanisms that influence intelli- gence and problem-solving. Processing speed, estimated by various reaction time tasks, is one of such mechanisms [8, 9]. To investigate the relationship between concurrent processing and processing speed we used the Simple Reaction Time task and calculated correlation coefficients between scores on the questionnaire on the ability to generate new thoughts and the variables derived from the Simple Reaction Time task.

Since the existence of the hypothesized mechanism is not obvious, to obtain reliable results we tried to maximize the number of participants. Therefore, freelancers took part in the study and each participant took part in the experimentation once. Each participant performed the questionnaire, problem-solving tasks, and the Simple Reaction Time task.

2. MATERIALS AND METHODS

2.1. Participants

A total of 475 participants (285 females, 190 males) aged from 13 to 64 years (M = 27.83; SD = 9.17) took part in the experimentation. The participants were recruited *via* Advego.ru, a Russian crowdsourcing system. The participants were paid US$0.8 for their work.

The experimental session was run online. The procedure of the experimentation was fully automated. Information on the experiment was added to Advego's list of active tasks and the task became available for all users of Advego. The design of Advego assured that each participant took part in the experimental session only once.

2.2. Materials

To evaluate the possibility of the emergence of supplementary ideas associated with the solution of a problem we worked out the Problem-Related Supplementary Thoughts Questionnaire (PRSTQ) that includes the following nine items:

1. *I think I am more likely than other people to have solutions to a problem coming to my mind on their own.*

2. *If I have found a way to solve a problem, it is unlikely that any other ways of the solution will occur to me on their own (reversed).*

3. *It is quite possible that after I have already solved the problem, more ways of solving it might occur to me.*

4. *Sometimes, new ideas might occur to me even when I am not solving the problem.*

5. *Sometimes I put off the final solution to a problem as more ways of solving it still might occur to me.*

6. *Sometimes, almost simultaneously, several ways to solve a problem can come into my head.*

7. *It is hardly the thing with me that new ways of solving a problem suddenly come to my mind (reversed).*

8. *If I keep thinking about a problem, a variety of ways to solve it might come to my mind.*

9. *Sometimes a solution to a problem would come to me at the most unexpected time and in unexpected places: while sleeping, waking up, on a walk, etc.*

A participant rated to what extent the item characterizes his/her. Responses were given on the following 5-point Likert scale:

1 = extremely uncharacteristic of me (not like me at all);

2 = partially uncharacteristic of me;

3 = neutral;

4 = partially characteristic of me;

5 =extremely characteristic of me (very similar to me)

The items of the questionnaire may lead to an assumption that the questionnaire is aimed at studying insight that is a suddenly emerging solution to the problem. Indeed, since a person is not aware of the mechanism invoking insight, insight can be considered to be the consequence of some hidden process which is parallel to the process that occupies the focus of consciousness. However, the researchers of insight consider insight a rare phenomenon [10, 11], but we believe that concurrent information processing is always involved in thinking. Accordingly, the statements of the questionnaire only characterize the frequency of the emergence of new and unexpected ideas associated with solving a problem. The items do not describe the situations in which those ideas arise, nor they evaluate its usefulness for finding a solution, nor they characterize emotions that accompany its appearance. The investigation of the relationship between concurrent processing and conventional insight is beyond the scope of this paper.

We do not consider the questionnaire to be a full-fledged psychometric scale but assume that the questionnaire may be useful to estimate the possibility of the generation of task-related, supplementary thoughts. If our experiment demonstrates that the PRSTQ scale is reliable then it is reasonable to suggest that a causal mechanism underpins responses of participants to the items. In this case the reliability and validity of the PRSTQ scale can investigated in new research. We designate this hypothetical mechanism the generator of task-related supplementary thoughts (GTRST) hereinafter. We do not suggest a prior that GTRST necessarily correspondents to a mechanism that processes information automatically and concurrently, GTRST may correspond to a deliberate, serial activity, theoretically.

Four tasks were used to examine correlations between responses to PRSTQ and the variables derived from problem-solving tasks.

One task was the Russian version [12] of the expanded version of the Cognitive Reflection Test (CRT) by Toplak, West, Stanovich [13] including seven problems. This task may be characterized as numerical and dual-processes are involved in the solution of these problems [14].

The second task was the Numerical Test (NT). This test included seven sequences that were borrowed from the Russian version of Eysenck's Numerical Test [15]. For example, the following sequences were used:

15 13 12 11 9 9 ?

The right response is 6.

4 7 9 11 14 15 19 ?

The right response is 19.

The aim of a participant was to continue the numerical series. The order of the presentation of the sequences was identical for all participants. This task can be characterized as numerical and related to fluid intelligence.

The common characteristic of these two tasks is that the tasks are complex. Indeed, to solve a CRT problem or a numerical sequence a participant should analyze the conditions, propose some hypotheses, test it through calculations, suggest new hypotheses, if necessary, *etc*. In other words, the procedure of solving such problems generates many thoughts. Although, we assume that GTRST corresponds to an automatic process, however the PRSTQ scale may be considered a measure of a metacognitive ability to monitor and evaluate own thoughts. It can be suggested that some people really delay the response to a problem because they experienced to monitor their thoughts continuously and hence, they believe that new ideas may come to mind yet. On the other hand, other people do not postpone the response because they do not expect novel ideas. As a result, a significant correlation between the PRSTQ scale and, for example, CRT may reflect individual differences in this metacognitive ability rather than those in concurrent processing.

To reduce a possible effect of the metacognitive ability we added two tasks that possibly generate fewer thoughts. One task was the Comparison of Two Words task in which 60 pairs of nouns were presented. For each pair it was necessary to mention whether both nouns designated animate objects, inanimate objects, or one noun designated an animate object and the other one did an inanimate object by selecting a position in the menu. There were 20 pairs for each selection. The order of presentation was randomized but identical for all participants. The pairs were prepared by the authors. The pairs were constructed so that the comparison of the nouns in each pair was not difficult. This task can be characterized as verbal and related to crystallized intelligence.

The other "easy" task was the Visual Search task. A string of 19 Russian letters was presented along with a probe letter, which was situated separately, for example:

ФЯТЬСЭБХЪПЦЕЩМЖВЗУЫ ____Я

The aim of a participant was to mention whether the probe letter was among the letters of the string by selecting a position in the menu. A total of 60 strings was presented, in 30 strings a probe letter was among the letters of the strings and it was absent in other 30 strings. The order of presentations was randomized but identical for all participants. This task can be characterized as verbal and spatial.

For all tasks all items were presented one at a time. There was no interval between the presentations of consecutive items. The number of the correct responses was considered the score on a task. The time taken to perform a task was considered the response time.

The following version of the Simple Reaction Time task was used: participants pressed on a button when they saw the symbol "A" on the display which appeared randomly in an interval from 1000 to 4000 milliseconds. There were five training probes and 40 test probes. If a participant pressed on the button prior to the appearance of the symbol such a response was ignored and another probe was presented until 40 probes were achieved. A mean and a standard deviation were calculated on the basis of 40 probes. Error rates were also calculated.

The order of the presentation of the tasks was as follows: the Problem-Related Supplementary Thoughts Questionnaire, the Comparison of Two Words task, the Visual Search task, the Numerical Test, the Cognitive Reflection Test, the Simple Reaction Time task. There was no interval between the tasks. There was no constraint on the duration of each task.

3. RESULTS

All participants performed PRSTQ and problem-solving tasks. 465 participants performed the Simple Reaction

Time task. Missing data were excluded from the analyses.

Cronbach's alpha for the Problem-Related Supplementary Thoughts Questionnaire scale was 0.705. This corresponds to a reliable scale therefore the sum of the rates on the nine items can be used as a score on this questionnaire. An average score was 33.14 (SD=5.5). An average score per item was 3.68, this number is higher than three that corresponds to the “neutral” rate of the items hence the phenomena described by the items really occurred in the thinking of participants.

A median response time for the Comparison of Two Words task was 4.87 seconds per pair of nouns. A median response time for the Visual Search task was 4.77 seconds per string. On the other hands, a median response time per problem for the Cognitive Reflection Test and the Numerical Test was 39 and 36 seconds, respectively. These results imply that the Comparison of Two Words task and the Visual Search task are, in fact, “easy” tasks and its performance may generate fewer thoughts per item than the performance of the “complex” tasks. A median reaction time was 0.548 seconds. A median standard deviation was 0.575 seconds and a median of error rates was 0 errors.

All correlations between scores were positive and a composite score was calculated as a sum of four z - standardized scores. A composite time of the performance of the four tasks was also calculated.

Correlation coefficients between PRSTQ scores, simple reaction times and the results of four tasks are presented in Table **1**. Since PRSTQ scores and simple reaction times had non-normal distributions (K-S d=0.0895, p<0.01 and K-S d=0. 1089, p<0.01), Spearman rank correlation coefficients were calculated.

Significant correlation coefficients between simple reaction times and times to complete the easy tasks are obviously a reflection of the fact that, since the easy tasks were performed quickly, the duration of its performance reflects individual differences in simple reaction times. Reaction times correlate negatively with scores on all tasks and significantly with the composite scores. Negative correlations between simple reaction times and general cognitive ability were obtained in many studies [16, 17]. Thus, our results reflect some general mechanisms.

There are significant correlations between PRSTQ scores and the variables derived from the Visual Search task. These correlations are similar to the correlation coefficients between PRSTQ scores and the results of performing more difficult tasks. We suggest this means that PRSTQ scores reflect the functioning of unconscious, automatic processes rather than the metacognitive strategies of participants. It is unlikely that the performance of the simple tasks could be accompanied by insights, therefore it can be considered that PRSTQ scores characterize mechanisms that are distinctive from mechanisms underpinning conventional insights.

Table **1** shows that all correlation coefficients between PRSTQ scores and the ten variables that were used to estimate problem-solving are positive and eight coefficients are significant. This indicates that GTRST exists and influences problem-solving.

Table **2** shows that all correlation coefficients are significant. However, if to calculate partial correlations between PRSTQ scores and reaction times and standard deviations then a partial correlation between PRSTQ scores and reaction times becomes insignificant (0.058, p=0.2) but a partial correlation between PRSTQ scores and standard deviations stays significant (-0.11, p=0.016). Since a correlation coefficient between average reaction times and standard deviations is very high, r = 0.98, to reduce the effects of multicollinearity we used ridge regression for the calculation of partial correlations [18]. The variance inflation factor (VIF) is usually considered a characteristic of multicollinearity. If VIF calculated for an independent variable is greater than five then the multicollinearity of the variable is high [19]. All VIFs computed in our analyses were less than five. Also, to normalize reaction times and standard deviations, for the calculation of partial calculations these variables were log10 transformed.

Table 1. Spearman rank correlation coefficients between PRSTQ scores, simple reaction times and the results of four tasks.

-	PRSTQ Scores (n=475)	Simple Reaction Times (n=465)
response times, Comparison of two words task	0.083	0.120**
Scores, Comparison of two words task	0.057	-0.060
Response times, visual search task	0.116*	0.155***
Scores, visual search task	0.216***	-0.002
Response times, numerical test	0.216***	-0.048
Scores, numerical test	0.144**	-0.193***
Response times, CRT	0.169***	-0.032
Scores, CRT	0.099*	-0.068
Composite performance times	0.188***	0.023
Composite scores	0.184***	-0.17***

Note: * - p <0.05; ** - p <0.01; *** - p < 0.001.

Table 2. Spearman rank correlation coefficients between PRSTQ scores and the parameters associated with the Simple Reaction Time task.

-	Reaction Times	Standard Deviations	Error Rates
PRSTQ scores	-0.093*	-0.128**	-0.202***

Note: * - p <0.05; ** - p <0.01; *** - p < 0.001.

Table 3. Spearman rank correlation coefficients between age and PRSTQ scores, the variables obtained from the simple reaction time task.

-	PRSTQ Scores	Reaction Times	Standard Deviations	Error Rates
Age	0.053	0.215***	0.182***	0.042

Note: *** - p<0.001.

As PRSTQ scores increase, all parameters associated with the Simple Reaction Time task decrease. This is another piece of evidence favoring a notion that the Problem-Related Supplementary Thoughts Questionnaire reflects more fundamental processes than the use of metacognitive strategies and processes associated with the emergence of insight.

Females scored on the PRSTQ scale marginally higher than males (33.55 *versus* 32.52 on average, t(483)=2.01, p=0.044, d=0.161). However, there were other differences between the genders in the study because females scored higher on the composite scores (0.319 *versus* -0.495, t(483)=3.19, p=0.0016, d=0.286). It is reasonable to suggest that the mechanisms underpinning responses to the PRSTQ scale may be slightly interconnected with the mechanisms underlying responses to other variables therefore gender differences on these variables may result in gender differences on the PRSTQ scale. To examine this suggestion, we computed the difference between the genders using the composite scores as a covariant. In this case, the difference between the genders became insignificant (F (1, 482) =2.3, p=0.13). It is reasonable to assume that there is no difference between males and females on the PRSTQ scale for the entire population.

Spearman rank correlation coefficients between age and PRSTQ scores and the variables obtained from the Simple Reaction Time task are presented in Table **3**.

Table **3** shows that a correlation coefficient between PRSTQ scores and age was positive, although not significant. This result is absolutely unexpected because, according to numerous studies, characteristics associated with the dynamism and variability of thinking (reaction time, working memory, fluid intelligence) tend to worsen with age [20-24]. Also, in our experiment the age of participants is positively and significantly correlated with reaction times.

It is important to note that if to calculate partial correlations between age and reaction times and standard deviations then a partial correlation between PRSTQ scores and average reaction times is significant (0.1, p=0.03) but the second partial correlation is not significant (-0.013, p=0.72). Both PRSTQ scores and standard deviations and error rates are stable over age, this is another piece of evidence that favors a notion that GTRST influences the dispersion of reaction times and error rates.

The relationship between age and the PRSTQ scores is presented in Fig. (**2**).

Looking at Fig. (**2**), it is not difficult to see that under 45 years of age the number of participants who scored on the PRSTQ scale high is approximately equal to the number of those who scored low. However, after 45 years of age those who scored high prevail.

4. DISCUSSION

The process of solving a problem is usually considered serial and conscious, when each intermediate representation, idea is a prerequisite for the next one until one of these representations matches the goal-state. However, numerous empirical facts demonstrates that sometimes some ideas regarding a problem come to the mind when the problem is absolutely beyond the focus of consciousness [25-27]. Such facts are the basis for various theories that posit two systems may be concurrently involved in problem-solving because the systems have different architectures. It is usually suggested that one system is preferably automatic and associative and the other system is preferably deliberate, rational, and reflective [28-30].

On the basis of a heuristic idea that thinking can be understood as processing information in a network of neuron-like elements that function concurrently, we hypothesize that concurrent information processing is always involved in problem-solving. Thus, the main distinction of our approach from other theories which assume the existence of concurrent processing is that we posit concurrent processing is possible within one system with slightly different elements. To examine this hypothesis, we designated a questionnaire on the possibility of the emergence of supplementary ideas associated with the solution of a problem and calculated correlations between scores on the questionnaire and the variables derived from four problem-solving tasks.

The results obtained in our study cannot be explained on the basis that the generator of task-related supplementary thoughts reflects the use of metacognitive

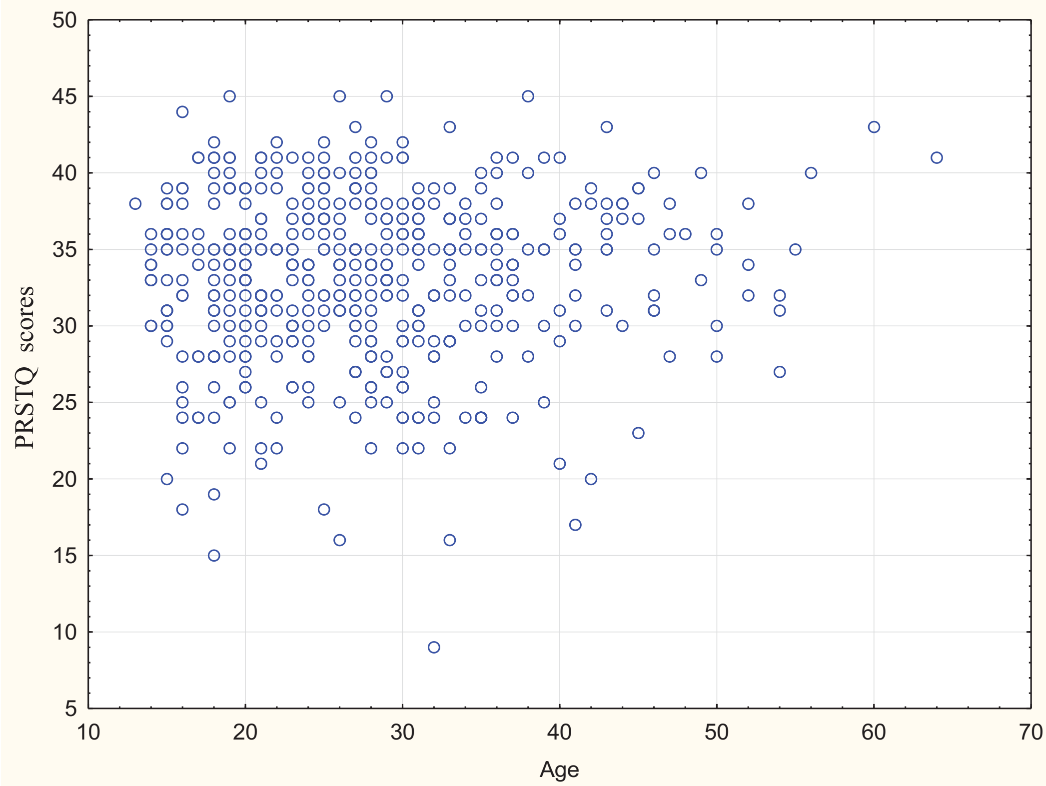

Fig. (2). The relationship between age and PRSTQ scores.

strategies and/or some mechanisms invoking conventional insight. The results do not seem entirely sufficient to reject an assumption that the generator reflects a sequential process however, the items of the questionnaire focus on the sudden and uncontrollable appearance of novel ideas and the emergence of new ideas in this way is unlikely to correspond to a sequential process.

As a result, we suggest that the generator corresponds to concurrent processing. We believe that our results confirm the hypothesis that concurrent information processing occurs in problem-solving. Although solving a problem seems to be a serial process when one idea, representation invokes a subsequent one, in reality several ideas are formed simultaneously. The formation of several ideas starts with the beginning of solving the problem. As is pointed out above, concurrent processing is a simple consequence of the idea that solving a problem is a process performed by a network of neuron-like units that function concurrently and each unit is connected with several others, but not with all units in the network. It is important to note that our approach does not contradict the suggestion that in some situations concurrent processing may result from the activation of several systems with different architectures. Indeed, despite different architectures such systems possibly can be understood as networks with the limited number of connections between elements.

We posit that concurrent processing always is involved in problem-solving, but its role may vary for different tasks and Table **1** demonstrates this. Table **1** also shows that the role of processing speed is also different for various tasks, although the association between processing speed and intelligence is established in various studies.

The existence of concurrent processing was also demonstrated in our other study [31].

PRSTQ scores do not correlate with simple reaction times and unlike simple reaction times, PRSTQ scores are not worsen over age. This means that concurrent processing and processing speed are based on distinctive mechanisms. Working memory is another mechanism that influences problem-solving and intelligence [32, 33]. In our paper [31] we found that PRSTQ scores significantly and positively correlated with working memory span for young participants, however such a correlation became insignificant over age.

The Simple Reaction Time task seems a primitive, practically automatic action, however, the situation is really more complex. Indeed, in this task a participant is instructed to press on the button as soon as possible when she/he sees the stimulus. This means the participant must maintain a high level of attentiveness and vigilance however avoiding pressing on the button when the stimulus is absent. On the other hand, the participant must immediately press on the button when the stimulus is present. It can be hypothesized that the instructions launch two concurrent processes. One process aims to inhibit pressing on the button, while the other process aims to activate such an action. These processes, obviously, interfere with each other. It is logical to assume that the stronger interference between these processes, the greater dispersion in reaction times and the higher error rates. The negative correlations between PRSTQ scores and standard deviations and error rates imply these processes interfere less if an individual scores on PRSTQ high. It is reasonable to assume that high PRSTQ scores reflect not only a high level of generation of concurrent processes but also a weak interference between concurrent processes in problem-solving.

An important parameter that determines the possibility of concurrent processes is the density of connections between the elements of a network. Obviously, if these connections are dense, that is, if each element in the network is connected with a large number of other elements, then the probability of the emergence of separate groups of elements that process information concurrently is low. However, if the connections are rare, then the probability of the emergence of several separate groups is much higher.

Several studies reveal that there is the decrease in the density of the white matter in the brain over age [34-36]. The white matter is the axons of neurons, that is, connections between the cells. Consequently, the connections between neurons in the brain become weaker and less frequent over age. If concurrent processes are inversely related to the density of connections, then an age-related decrease in density explains why scores on the PRSTQ scale are stable over age.

Fig. (**2**) demonstrates that among the participants who were older 45 years, high scores on the PRSTQ scale prevailed. The participation in crowdsourcing requires a relatively high level of intelligence and good computer skills and since an average age in the sample was 27.83 years, 25 participants who were older 45 years probably estimated their intelligence and computer skills above average. Indeed, their median composite score was 1.231 and 460 participants not older than 45 years scored 0.067 only. A median PRSTQ score of the elder participants was 35 and the younger participants scored 34. However, a median reaction time of the younger participants was faster: 0.544 seconds *versus* 0.572 seconds. This implies that for some people, the high and stable level of concurrent processing compensates for the age-related decrement in other cognitive mechanisms.

Novel studies on concurrent processing are necessary. We investigated the role of concurrent processing for verbal and numerical tasks, however, the role of concurrent processing for other kinds of tasks needs new research. It is of interest to study concurrent processing in various situations such as stressful or anxious, when the interference between concurrent processes may distinguish from its standard level. Since the notion of concurrent processing is based on the heuristic use of neural data, the investigation of the relation- ship between concurrent processing and brain processes is important.

It is necessary to mention the limitations of our research. Four tasks were applied to study the relationship between concurrent processing and problem-solving. It is possible that the use of other tasks may seriously change correlations between the variables derived from those tasks and PRSTQ scores. The Simple Reaction Time task was used to evaluate processing speed. However, it is possible that this task reflects processing speed incompletely and other tasks for example, the multiple choices reaction time task should be more appropriate. In this case the correlations between the PRSTQ scale and the variables derived from such tasks may be distinctive from the correlations obtained in the current study. Recruiting participants at crowdsourcing systems may result in some biases. There was a bias in our sample regarding genders because males scored on the composite scores lower than females. Also, our participants were younger than the entire population. It is possible that concurrent processing functions differently in the elderly.

CONCLUSION

Following a heuristic idea that thinking can be understood as processing information in a network of neuron-like elements that function concurrently, we hypothesize that concurrent information processing occurs in problem-solving. We believe that our research demonstrates the existence of concurrent processing in problem-solving. It is demonstrated that the mechanism of concurrent processing is distinctive from the mechanism of processing speed. An explanation for the fact that unlike other characteristics associated with the dynamism and flexibility in thinking, concurrent processing is not worsened with age is suggested.

AUTHORS' CONTRIBUTION

P. N. P.: Study Concept or Design; O. N. R.: Data Collection

LIST OF ABBREVIATIONS

PRSTQ = Problem-Related Supplementary Thoughts Questionnaire

GTRST = Generator of Task-related Supplementary Thoughts

CRT = Cognitive Reflection Test

NT = Numerical Test

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The experiment was approved by the ethics committee of the psychology department of Lomonosov University, Russian Federation.

HUMAN AND ANIMAL RIGHTS

All procedures performed in studies involving human participants were in accordance with the ethical standards of institutional and/or research committees and with the 1975 Declaration of Helsinki, as revised in 2013.

CONSENT FOR PUBLICATION

Informed consent was obtained from all participants of this study.

STANDARDS OF REPORTING

STROBE and SAGER guidelines were followed.

AVAILABILITY OF DATA AND MATERIALS

The data supporting the findings of the article is available in figshare at https://figshare.com/articles/dataset/Experimental_Data_for_Article_xlsx/25411588?file=45043651 reference number 25411588.

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CONFLICT OF INTEREST

The authors declare no conflict of interest financial or otherwise.

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Declared none.

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