Cognitive Flexibility

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1 DEFINITION

Cognitive flexibility is the human ability to adapt the cognitive processing strategies to face new and unexpected conditions in the environment (Cañas *et al*. 2003). This definition involves three important concept characteristics. Firstly, Cognitive Flexibility is an ability which could imply a process of learning, that is, it could be acquired with experience. Secondly, Cognitive Flexibility involves the adaptation of cognitive processing strategies. A strategy, in the context of this definition, is a sequence of operations which search through a problem space (Payne *et al*. 1993). Cognitive flexibility, therefore, refers to changes in complex behaviors, and not in discrete responses. Finally, the adaptation will occur to new and unexpected environmental changes after a person has been performing a task for some time.

Although flexibility could be an adaptive capacity of individuals (Payne *et al*. 1993), this adaptation does not always happen. In situations where a person should be flexible in order to deal with changes in the environment, but fails to do so, we speak of cognitive inflexibility. An example of this inflexibility occurs when actions that have shown to be effective in previous situations are insistently carried out in new situations where they are ineffective. For instance, imagine that we are inside a room and try persistently to open the door by pulling it (as it is normally the case), but the door remains closed. We could think that the door is broken instead of trying to open the door by pushing it. What is the problem? It is possible that we are not addressing the lack of space inside the room or that we do not know that in these kinds of buildings doors open in a different way. Research on cognitive flexibility and cognitive inflexibility has led to the proposal of explicative hypotheses of these phenomena. We will consider all of these in the following section.

2 EXPLICATIVE HYPOTHESIS OF COGNITIVE FLEXIBILITY

When a person performs a complex task their behavior needs to be adapted to the environmental conditions in which the task is being performed. However, these conditions continue to change as the task develops, therefore in order to be flexible, a person has to focus attention on these conditions on a regular basis. In addition to this, in order to adapt their behavior to the new conditions, the person needs to restructure their knowledge so as to effectively interpret the new situation and the new task requirements. Cognitive flexibility, therefore, depends on attentional processes and knowledge representation.

On the one hand, cognitive flexibility crucially depends on attentional processes. In detecting that a situation has changed and the necessities of a nonroutine response, a higher level of attentional control is needed, where the person assesses the new situation and plans the action to be taken. To be cognitively flexible, a person needs to perceive the environmental conditions that could interfere with the task at hand. In addition to this, there is a need to invest resources in aborting an automatic response and, therefore, to plan a new sequence of corresponding actions that effectively address the new task demands.

On the other hand, cognitive flexibility also refers to how people represent their knowledge about a task and the possible strategies in which to engage with. Human behavior is controlled by a person's knowledge regarding the values of the environmental parameters. This knowledge has been obtained by means of learning from previous similar situations. However, this knowledge has to be modified when the situation changes in order to reinterpret possible new task requirements. It is in this sense that Spiro and Jehng (1990) has proposed the Cognitive Flexibility Theory according to which people who pose a representation of the task from multiple perspectives can easily interpret situational changes in the environment and, therefore, can be more cognitively flexible. These people, therefore, have the ability to quickly restructure their knowledge, hence adapting their responses to radically changing situational demands.

These two explanations complement each other, that is to say, therefore, that in being cognitively flexible, a person needs to both address and interpret the new situation, restructuring their knowledge in order to adapt their behavioral strategies accordingly.

3 COGNITIVE FLEXIBILITY, EXPERTISE, AND HUMAN ERROR

When a person is not cognitively flexible, they behave in a nonfunctional way in dealing with situational demands, therefore they would often perform erroneously. For this reason, different research areas have used this phenomenon to explain particular experts errors.

Some authors have concluded that experts tend to be more cognitively inflexible (i.e. Anzai and Yokoyama 1984; Frensch and Sternberg 1989), and, indeed, empirical research has shown that inflexibility and expertise are intrinsically united (Frensch and Sternberg 1989). It is also thought that experts change their mental representations of tasks less often than novices (Anzai and Yokoyama 1984). In general, these authors assume that when a person knows that they are skilful, they are less likely to change their strategy after detecting significant changes, and/or they are also less able to detect them in the first place. When experts rely on automated performance routines, therefore, they are less able to judge the likelihood of a failure in a system (Edland *et al*. 2000).

However, it has been argued that these theories do not make any assumptions about which environmental changes would affect performance once a person has automated their performance, and moreover, implicitly assume that any change leads to cognitive inflexibility. That is to say, these theories assume that the only important factor in determining the drop in performance is the degree of automatization of behavior. Therefore, this explanation appears to be insufficient, as in interactions with the environment, experts are exposed to a huge variety of changes and their performance is negatively affected by only a few of these changes.

Some authors in cognitive psychology defend the reverse hypothesis. For example, research conducted by Spiro and Jehng (1990) suggested that a prominent expert characteristic is the ability to manipulate multifaceted mental representations, therefore permitting a better adjustment to environmental changes and a greater transfer of AQ1 knowledge between tasks. Reder and Schunn (1999) have also found that participants that have performed better in a dynamic task differ from those with worse performance mainly in their capacity to adapt their behavioral strategies to the changes in the conditions of the tasks, and not in the repertoire of strategies, nor in the ability to execute a particular strategy. However, the problems with these theories is that they do not explain why experts are cognitively inflexible in some situations (Edland *et al*. 2000).

These two hypotheses could be true: experts can have more difficulties attending to and perceiving environmental changes, however, after noticing changes, they can modify their mental representations more efficiently in order to adapt their corresponding behavior. The question of when we can expect to observe an expert being cognitively inflexible has to be answered considering Canas *et al*. (2003) suggestion. According to these authors, cognitive flexibility depends on whether the environmental changes a person faces are important for the particular strategy that the person has developed during learning. Only those changes that are important for a person's strategy would affect their performance. The authors based this hypothesis on the ecological theory of expertise by Vicente and AQ1 Wang (1998) known as the Constraint Attunement Hypothesis (CAH). In brief, this theory proposes that the acquisition of skills should be understood as the adaptation to the constraints imposed by the environment. People develop different strategies to adapt to these constraints, and each developed strategy depends on different environmental characteristics. Therefore, only those changes that affect a particular strategy that a person is using would affect their performance. Within this framework the question has to be reformulated, and as a result, the focus is not only on the processes responsible for cognitive flexibility, but also on which environmental constraints are important, and in combination with which process would determine when we can observe cognitive flexibility. Therefore, on occasions, the change, although it has not been detected, will be irrelevant and will not affect behavior effectiveness, hence we cannot observe cognitive inflexibility in the expert behavior. However, on other occasions, that particular environmental change might be important for the task or the action that has been put into practice, hence the effectiveness of expert behavior will be affected. On these occasions, the person must address and interpret the environmental change accordingly and then modify their representation in order to adapt their behavior effectively.

4 SOME PHENOMENA RELATED TO COGNITIVE FLEXIBILITY

The concept of cognitive flexibility, especially its counterpart cognitive inflexibility, is related to four other concepts that have been studied in the Psychology of Thinking: cognitive blockade, cognitive hysteresis, functional fixation, and functional reduction.

Cognitive blockade is defined as a tendency to continue with an initial course of action, even in situations where it is rational to change to an alternative course of action. The person focuses their attention to a part of the activity that they are performing and shows a limitation to distribute their time among other concurrent activities. When a bad operation has multiple effects, the person has to make a deliberate choice so as to be able to control the shortcomings in a sequential way.

This phenomenon is related with cognitive inflexibility. As we have seen in cognitive blockade, the person seems to be focused on certain aspects of the task and ignoring others, as a consequence they continue with the course of action that they were carrying out. In the case of cognitive inflexibility, the person continues with the same strategy that they have been using even though the conditions have changed. This allows us to consider that cognitive inflexibility is a form of cognitive blockade. Although we will reserve the term of cognitive inflexibility for the situations in which cognitive blockade affects an entire strategy, that is to say, a pattern of actions and decisions.

Cognitive hysteresis, another phenomenon related to cognitive inflexibility, is defined as the tendency to adhere to a decision after evidence has proven it to be a mistake. This is also known as cognitive narrowing, or tunnel vision, and it is usually explained as a failure in the process of reevaluating a situation after a decision on how to deal with it has been made.

This phenomenon, although related to cognitive inflexibility, highlights the existence of a false diagnosis of the situation. In the phenomenon of cognitive inflexibility, however, the stress is made on the mistaken activity that the person carries out in order to solve the problem. That is to say, although when observing cognitive inflexibility we can be in a situation that has its cause in a false diagnosis, the cause is on the activity and not on the diagnosis that originates it. This distinction is important because it is possible that we observe cognitive inflexibility that does not have its origin in a false diagnosis.

A third phenomenon is functional fixation which is defined as the tendency to consider only the available objects in a task as known in terms of its more common function. People have difficulties using elements that have taken a new form. This happens because we tend to put elements into categories to which they were previously assigned, and this, therefore, leads us to believe that the elements only possess the properties that were assigned to that particular category. Functional fixation means that we are fixed or rigid in our perceptions, including in the use of daily objects. This rigidity inhibits our ability to see how these objects can be used in new ways.

The phenomenon of functional fixation is related to cognitive inflexibility in the sense that they both have similar effects, since both result in an impossibility to use the available resources with the objective of overcoming the barriers that are between the current state and the desired state. The difference is that to overcome functional fixation it is necessary to find a new function for the elements that are being used. However, in the case of cognitive inflexibility it is not necessary to find a new function but to use the same elements with the same functions but with a different strategy. That is to say, what is needed is to use them in a different sequence, in different areas of action, or with a frequency of use for each function different to the one that has been used before.

Finally, functional reduction, a forth phenomenon related to cognitive inflexibility, has been defined as the tendency to face a problem sticking to a single cause whilst neglecting all other possible influencing variables. Several modalities of functional reduction can be presented. The most general case consists of reducing the different causes of a problem to one single problem. In this case, functional reduction produces similar effects to cognitive inflexibility, that is, an inability to adapt behavior to the environmental conditions that a person faces. However, cognitive inflexibility does not have to be produced by a decrease in the possible causes that are generating the changes.

These phenomena, therefore, share the same observable behavioral effects with cognitive inflexibility. These four phenomena lead to a fixed action or they impede the solution of a problem, as in cognitive inflexibility whose fundamental effects consist of continuing with a strategy that has been used until that moment, but that under the current conditions does not produce good results. However, there are important aspects that differentiate them. They vary in the explanations that have been offered for the errors that we observe on behavior. Although these explanations are different, they all still have the same point in common: they propose the existence of a failure in the evaluation of the situation that leads to a failure in its execution. In the case of cognitive blockade, this failure consists of the loss of a global diagnosis of the situation, as it is centered in concrete aspects. In cognitive hysteresis, the failure lies in the fixation on an erroneous diagnosis due to the difficulties in evaluating the situation with new pieces of evidence. In the case of functional fixation, the cause of the failure is the fixed assignment of an object to a category, hence conditioning the properties that are assigned to that object. Finally, functional reduction takes place when we consider, only in part, the causes that produce a phenomenon.

The explanation of the phenomenon in terms of cognitive inflexibility is centered on the automation processes that begin after extensive practice within the task. In this situation, behavior is controlled by processes that require fewer resources and that lesser supervise the possible changes that are taking place in the environment. Unexpected or stranger demands in the situation force the person to introduce other forms of control or conscious behavior. A failure in this process can produce the phenomenon known as cognitive inflexibility.

5 COGNITIVE FLEXIBILITY TRAINING

The main goal of most skill training programs consists of automating skill in order to speed performance and save cognitive resources for other task demands. However, as explained above, the automation of a skill can be associated to cognitive inflexibility and performance errors. For this reason, different training programs have been proposed in order to overcome performance problems associated to automation. These programs come from two cognitive explanations of the cognitive flexibility phenomenon: knowledge representation and attentional processes hypotheses.

One set of programs has followed the knowledge representation hypothesis that focuses on the reorganization of knowledge to explain how we adapt to new situations. The main idea behind these programs consists of emphasizing irregularity and variation in training over a fixed repetition of steps. This variability can be obtained by means of different training scenarios with different demands, or by increasing the training of different behavioral strategies in different sequence orders. Research in complex problem solving has shown some examples of this type of program.
AQ2 Antoli *et al*. (in press) present an experiment in which participants were provided with a problem solving task simulating a fire fighter commander in two different training blocks: one group practiced the task over several trials using the same task scenario, and the other group practiced the task in different task scenarios. The scenarios represented an open forest on fire, and the participant task consisted of stopping the fire using different strategies that were taught in advance: dropping water from helicopters or trucks, and making control fires with trucks. The variability of the scenarios came from the different variables available to the participants, such as wind speed and direction, water effectiveness, or type of land. After the learning period, both groups of participants were presented with identical scenarios, although different from those used in the learning phase. Results revealed that participants in the variable training group changed strategies more often when faced with new task demands during the experimental phase, whereas the nonvariable group tended to repeat the same strategy practiced during the learning phase. The negative consequences of this kind of training could explain the great amount of resources that have to be invested due to continual environmental changes. In these cases it is necessary to balance the need for automatization and efficiency and that of prevention of errors.

Under some circumstances, however, learners cannot be exposed to all the possible scenarios of a particular task. In this situation, a different approach is needed allowing for cognitive flexibility training without the need for training people through different scenarios. This is the reason for a second group of programs that have been derived from the attentional processing hypothesis. The idea behind these programs is that people are unable to adapt to a new situation due to a lack of ability to change attentional control to the important requirements of the new situation. In these programs, learners are instructed to vary the amount of attention (i.e. effort) dedicated to different tasks features during the training session. For example, in a task consisting of several sub-tasks involving the continued exploration of several displays, operators are told to switch their priorities from display to display through different training blocks. The objective of this training is to improve the efficiency of the disengagement of attention from one sub-task to another. This type of training has been proven to provide improved performance and skill transfer to new situations than the type of training that consists of learning each sub-task at a time, or practicing the task at the same time without priority instruction (Kramer *et al*. 1995).

Therefore, the effectiveness of the training programs for improving cognitive flexibility would depend on the type of task at hand. Firstly, programs stressing variability in training can be appropriate for improving cognitive flexibility in learning situations, allowing the learner to practice with a representative set of different task situations. Secondly, programs focusing on attentional disengagement could be useful in tasks involving a clear set of different sub-tasks, such as dual tasks.

6 NEUROPSYCHOLOGICAL BASES OF COGNITIVE FLEXIBILITY

The main characteristic of cognitive flexibility is the occurrence of a change or shift in the attentional control level, or in the representation of a task which leads to a change in the strategy performed. The central executive is the cognitive structure which has been thought to be involved in such processes of change. Therefore, similar neurological substratum related to executive functioning (prefrontal cortex and its circuitry) has been proposed as the neuropsychological base of cognitive flexibility. For example, in an event-related fMRI study (Schmitz *et al*. 2003), it has been demonstrated that when individuals with Asperger's AQ3 Syndrome, who may have a dysfunction of the medial frontal gyrus and the superior parietal lobe areas, perform cognitive flexibility tasks (tasks of set-shifting), they show significantly more activation in those areas. In addition to this, after an examination of two groups of injured people (focal ischemic lesions to the frontal lobe and basal ganglia) (Eslinger and Grattan 1993), it was found that the frontal lobe appears to mainly mediate a concrete form of cognitive flexibility, the spontaneous flexibility, a concept more related to the production of diverse ideas and to the access of knowledge systems with novel strategies distinct from most common semantic linkages (related to the representational hypothesis). In contrast with this, the corticostriate system (basal ganglia and their interconnections) together with the frontal lobe appears to mediate reactive flexibility, shifting response set (related to the attentional hypothesis).

Therefore, within the neuropsychological research, support can be found for the two explicative hypotheses of the flexibility phenomena, since brain regions involved in both attentional shifting and access to knowledge systems mediate diverse forms of cognitive flexibility tasks.

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AQ1: Please add the Reference "Reder and Schunn (1999) Vicente and Wang (1998)" to the list.
AQ2: The Reference "Antoli *et al.* (2004)" has been changed to "Antoli *et al*. (in press)." as per the reference list. Please check.
AQ3: The Reference "Schmitz *et al*. 1993" has been changed to "Schmitz *et al*. 2003" as per the reference list. Please check.
AQ4: Please update Reference for "Antoli *et al*. (in press)."
AQ5: Please check if detailed information can be provided for the reference "Schmitz *et al*. 2003."