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Structuring Effect of Tools conceptualized through Initial Goal Fixedness for work activity

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Abstract

Analysis of work activities in nuclear industry have highlighted a new psycho-cognitive phenomenon: the Structuring Effect of Tools (SET) sometimes leading to unexpected operating deviations; the subject is unable to perform a task concerning object A using or adapting a tool designed and presented to perform the same task concerning object B when object A is expected by the subject. Conditions to isolate and identify the SET were determined and reproduced in experiments for further analysis. Students and seven professional categories of adults (*N*=77) were involved in three experimental conditions (control group, group with prior warning, group with final control) whilst individually performing a task with similar characteristics compared to real operating conditions and under moderate time-pressure. The results were: i) highest performance with prior warning, ii) demonstration that academic and professional training favor the SET. After discussing different cognitive processes potentially related to the SET, we described iii) the psycho-cognitive process underlying the SET: Initial Goal Fixedness (IGF), a combination of the anchoring of the initial goal of the activity with a focus on the features of the initial goal favored by an Einstellung effect. This suggested coping with the negative effect of the SET by impeding the IGF rather than trying to increase the subjects' awareness at the expense of their health. Extensions to other high risk industries were discussed.

(wc=222)

Keywords : Performance; Fixedness; Attentional control; Flexibility

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1. INTRODUCTION

1.1. Operation and safety constrained design

Exploitation of high risk industrial socio-technical systems implies a high level of safety and of work activity reliability. For example, regarding nuclear industry, the production division of Electricite de France (EDF) always tries to find organizational solutions in order to reinforce these lines (see for example: Le Bot, 2004; Fauquet, 2007, 2008). In parallel, the French national regulator, involved in the same safety concerns, permanently watches the ways plants are operated and has specific requirements aiming at contributing to a higher level of safety. Careful analyses carried out of safety events in the nuclear power plants (NPP) produces recommendations that are integrated in procedures. Safety events are undesirable technical or organizational events where their occurrence combined with other factors could bring the control of the installation into question. Yet, when these recommendations are combined with the integration of the aforementioned requirements of the regulator, this may sometimes result in difficulties in applying procedures: they integrate information to perform the task, information to respect the operational and safety requirements (Buessard & Fauquet, 2002), and additional information resulting in the feedback issued from the safety event analysis (Fauquet, 2004). Furthermore, procedures may be polluted by operating details due to the belief that it is possible to put know-how and skills in writing. After more than 10 years of existence, the final procedures may be four times the volume of what is strictly necessary to understand how to carry out the task, and may lead workers to "cook the books" rather than understanding what they do. In this case, the risk of being engaged in an uncontrolled structured manner to perform the task becomes possible without being able to notice and deal with an unplanned detail that may result in a mistake or an error. This yields to explicit or implicit regulations that constrain actions and interactions within the socio-technical system (Hasu & Engestrom, 2000; Béguin & Clot, 2004; Bruno & Munoz, 2010). We can see that, paradoxically, what is implemented in the aim of reinforcing safety and reliability may thwart these goals in certain conditions. These concerns led event analysts at Chinon NPP (Fauquet-Alekhine & Boucherand, 2011; Fauquet-Alekhine, 2011) to focus on events involving the use and application of procedures. They discovered that, amongst the safety events involving causal factors linked with the application of procedures, up to 50% presented similar and surprising contextual features (hereinafter referred to as the "SET conditions"):

- the workers were individually involved in one activity,
- were experienced in their position,
- were perceived as trustful and conscientious by their managers and peers,
- knew the activity well having already performed it several times,
- could explain exactly what they had to do during the activity afterwards,
- claimed afterwards they knew what to do when they performed this activity,
- were not distracted during their activity,
- were not stressed as there were no high stakes concerning their task and not specially pressed by time.

When they were asked to describe what they meant regarding this last point, they explained that they had to do their job quickly as further tasks were expected of them, but there was no rigid deadline to achieve the activity and there was no emergency. In other words, on a three-level scale (see appendix) regarding time pressure (low, moderate and high), the analysts concluded that the time pressure level was between low and moderate. Some of these safety events involving the use of procedure were explained by an unconscious shifting of the objective of the activity. This phenomenon has been studied and conceptualized elsewhere (Fauquet-Alekhine, 2012c). The remaining events were seen as a possible result of a structuring effect of the procedure, the tool used to perform the task. To illustrate this finding concretely, an example is given hereafter.

Example #A: “power variation” [2-121609] In the control room of the nuclear reactor, the pilot (15 years experience) was using a procedure in order to increase the neutronic power of the reactor and had to respect the gradient to reduce possible interaction between the fuel pellets and the sheath inside the core. Only positive slopes were taken into account by the pilot (corresponding to increasing power) although he knew he should have taken both positive and negative slopes into account. Over the last 12 months, this kind of deviation had happened several times in the same conditions and with different subjects. Nothing indicated what made the pilot acting this way except an assumption regarding the structuring effect of the procedure.

Alerted by this atypical context involving the structuring effect of tools, analysts decided to identify previous similar cases implicating other kinds of tools.

Tools may take many forms. The Merriam-Webster dictionary suggests that a tool is i) a handheld device that aids in accomplishing a task, ii) something (such as an instrument or apparatus) used in performing an operation or necessary in the practice of an occupation or profession, iii) an element of a computer program (such as a graphics application) that activates and controls a particular function, iv) someone that is used or manipulated by another. We may summarize these possibilities as follows: a tool is an interface between the subject (the one who plans the action of transformation) and the object of work (that which will be transformed according to the subject's act). It establishes the relationship: subject-tool-object of work where the tool is a mediator. This joins the concept of artifacts and their mediating role within the activity suggested by the Activity Theory (Leontiev, 1974; Nardi, 1995). Bibliographic research concerning the term "tool" in the title of the articles suggests many other meanings; these are a few examples: a method of analysis (Leontiev, 2001/2006; Bernstein & Boyden, 2012), the law (Nardi, 1995), a medical placebo (Bishop et al., 2012), analytical models (Brekke & Moxnesb, 2003; Lavya & Shrikib, 2010), management and evaluation tools (Maggin et al., 2011; Samuel & Tenenbaum, 2011; Shipman et al., 2012), training and interactive tools (Leshcheva et al., 2010; Meyer, 2010; Rodrıguez et al., 2011), decision support (Perimenis et al., 2011) and organizational tools (Sujan, 2012; Torija et al., 2012).

When reinvestigating safety reports over four years (2009 to 2012) focusing especially on events presenting the aforementioned "SET conditions", an average occurrence of 5.75 per year was found for events possibly linked to a structuring effect of the mediating artifact (the tool) between the subject and the object of work. Here are some examples of similar cases of structuring effect with different tools.

Example #B: "relay rack" [ref: 1-050510] The automatism technician used a mobile electronic device to perform a periodic test and applied the instructions read on the screen of the device on a rack although it concerned another rack; he did so despite having doubts while reading the instructions and despite what was written on a paper procedure he had with him but did not used. The subject explained afterwards that he concentrated his attention on what was required by the electronic device. This led to an automatic scram. The object of work was the relay rack and the mediating tool was the electronic device.

Example #C: "core temperature" [3-082011] An operating team manager (10 years experience) verified the reporting section of a procedure of periodic test, involving several tens of values. The verification concerned the nature of the values and their correctness. When checking the temperature of the nuclear core, the value was

checked by the manager but not its nature. The manager therefore did not notice that the temperature of the tank cover was reordered rather than that of the tank itself although he knew perfectly well that the latter should have been used. Afterwards, the manager explained that he had probably focused on as little information as possible certainly to be more efficient. Despite the absence of consequence on the process, this was a deviation from the expected quality. Nothing could explain this deviation except the assumed contribution of the structuring effect of tools. The object of work was the reporting section of the procedure and the mediating tool was the mental protocol applied to verify the report.

Regarding the French nuclear industry, the possible drawback of the Structuring Effect of Tools has given rise to operational solutions (Le Bot, 2004; Fauquet, 2007; Theurier, 2010; Fauquet-Alekhine, 2010, 2012a; Fauquet-Alekhine et al., 2012) based on Rasmussen's SRK model (Rasmussen, 1983; Rasmussen et al., 1994, 2000) and considering the "SET conditions" as involving workers in routine activities (AIAE, 2002; INPO, 2015). The "SET conditions" were considered to produce Skill-based behavior (S of SRK), occurring when the context offers the subject all cues needed to know which action to be applied, taking "place without conscious control as smooth, automated, and highly integrated patterns of behavior" (Rasmussen, 1983: 258), and applying "during familiar circumstances," when "sensory-motor routines take care of the direct control of integrated patterns of movements" (Rasmussen & Svedung, 2000: 61). "Characteristically, skilled performance rolls along without conscious attention or control" (Rasmussen, 1983: 259). This level is therefore characterized by the application of routines with a low degree of attentional control in the context of very familiar activities.

The investigation of safety reports showed that associated kind of safety events then significantly decreased in 2012 and there were no cases in 2013 nor in the first semester of 2014 (further data is not yet available). However this improvement came with the conjunction of two factors: i) application of operational solutions, ii) high staff-turnover with a large decrease in the number of experienced workers (Fauquet-Alekhine, 2015). The first point suggested that organization coped with the problem but the second point suggested that it became more difficult to detect the "SET conditions": the features "were experienced in their position", "knew the activity well having already performed it several times", "could explain exactly what they had to do during the activity afterwards" and "claimed afterwards they knew what to do when they performed this activity" were no longer encountered. Therefore, the reduction in SET events might be seen as a temporary reduction and this suggests the reappearance of

the phenomenon in a few years. We could also assume that the SET remained present in activities but its detection was made more difficult as the conditions favoring an easy identification were not fulfilled.

These concerns led us to try to improve understanding of the phenomenon which has not yet been conceptualized according to bibliographic research. This paper aims at proposing the theoretical key points of the Structural Effect of Tools based on a previous study (Fauquet-Alekhine & Boucherand, 2012) enriched with additional experiments. The results might serve as a basis in order to enhance new solutions to cope with the Structural Effect of Tools.

1.2. Structuring effect of tools and previous study

Based on work activities observations and analyses, the Structuring Effect of Tools (SET) has been commented in a previous study (Fauquet-Alekhine & Boucherand, 2012): "sometimes workers could be involved in a human error or a deviation leading to a major (or significant) event even when they were updated regarding the task, were experienced, were well-informed about the activity, knew everything about the job, were not too self-confident. Indeed, nothing could explain the result except making the assumption that the tools used to perform the task under time-pressure could have led them to the event" (p. 63). More concisely, the SET appears to be the restriction of the subject's field of consciousness whilst performing a work activity with contextual features referred to as "SET conditions" in section 1.1 favoring this structuring effect.

The SET being an observable phenomenon, we conducted experiments in the aforementioned previous study to determine whether or not there was a link between the SET and workers' academic or professional training. "The assumption that some professions or academic background could have such an outcome was made after specific training sessions involving groups of workers taking psycho-technical tests: it appeared for example that some professions were more successful taking a test involving the Stroop effect [Stroop, 1935] than others" (p.63). In other words, we sought whether or not there was a specific academic background of a particular professional experience that could help the worker not to be trapped by the SET. For this aim, we invited workers of seven different professions in nuclear industry plus an additional category of students to individually take a test with a time limit, called thereafter the "Letter-test". The task was simple: it consisted in counting the letters which height was less or equal to 5 mm on five boards, each board made up of 3 lines of letters (Figure 1). For this purpose, the subjects were given two different tools: the classic ruler or a mask presented as specifically designed for the task

(Figure 2). The subjects had to choose one of the two tools before beginning to perform the task, but could exchange tools as they wanted during the activity. The design of the Letter-test was made in order to put subjects in similar "SET conditions" to those encountered in the aforementioned events observed on Chinon NPP: subjects were individually involved in one activity, were experienced regarding the proposed task, were perceived as conscientious by the experimenters, could explain exactly what they had to do during the activity afterwards, claimed afterwards they knew what to do when they performed this activity, were not distracted during their activity, were not stressed as there were no high stakes concerning their task and were submitted to low to moderate time pressure having being told that their activity was being timed. The "SET conditions" defined the controlled variables, the professional experience and academic background were the dependent variables and the independent variable was the performance.

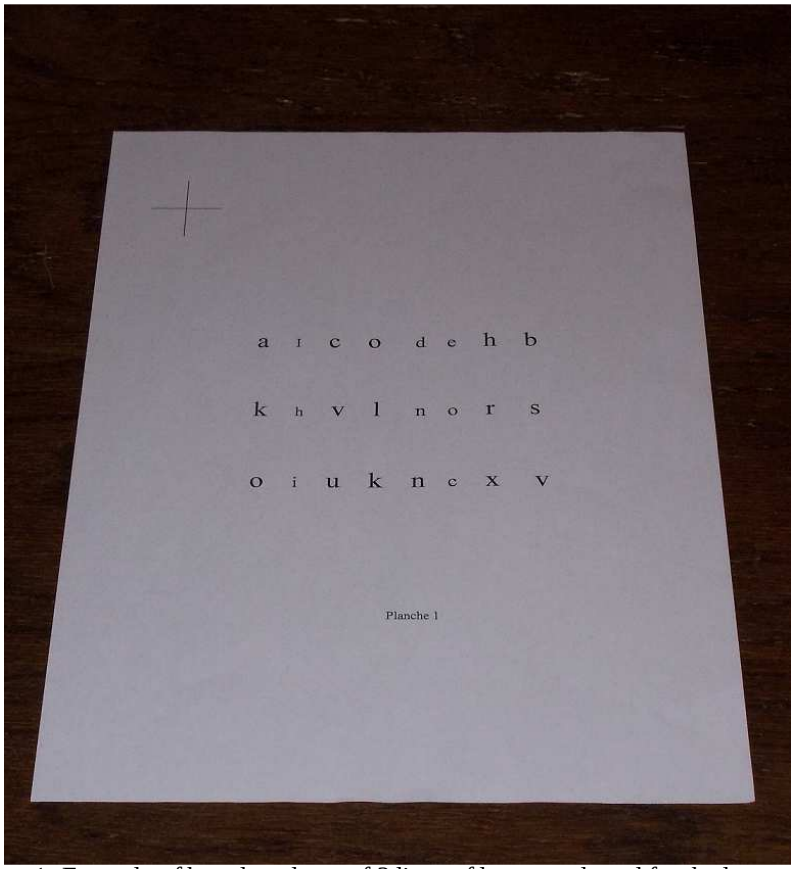

Figure 1: Example of board made up of 3 lines of letters and used for the letter-test.

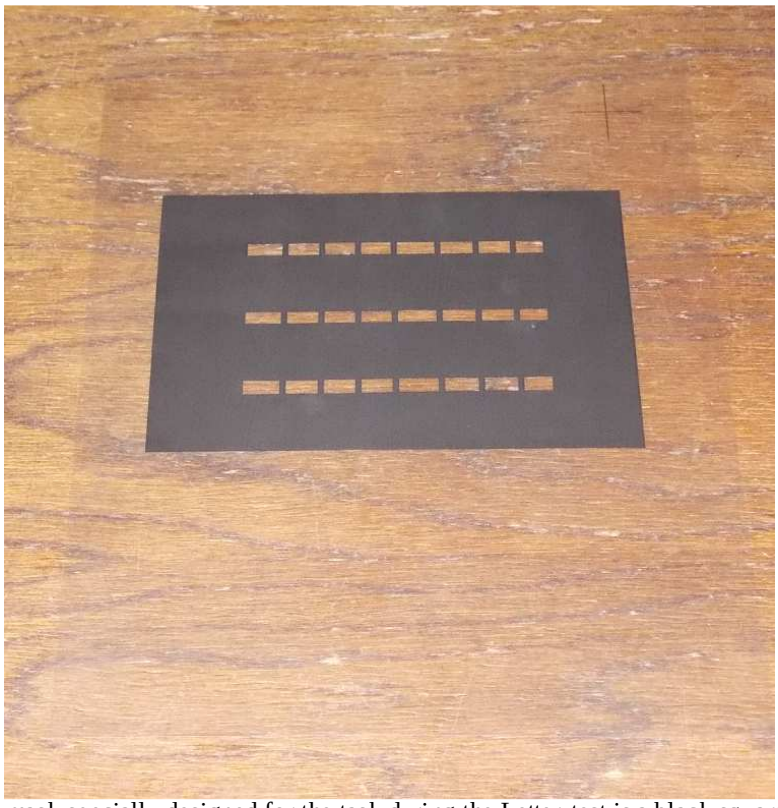

Figure 2: The mask specially designed for the task during the Letter-test is a black square printed on a transparent slide with three lines of windows.

The experimental condition in which the Letter-test was taken is called the "one-by-one" condition: the subjects had to check each board without seeing the others, and when they gave the board back to the researcher, another one was given to them but they were not allowed to watch again the previous one. At the end of the test, all the boards were gathered and the subjects were not allowed to see them anymore. The trap resided in the fact that each line of the last board had an extra letter (9 letters per line instead of 8) which could not been seen using the mask.

The result was 11% success (success meaning the ninth letter was dealt with and all counts were right) for all categories (N=57) and the proportion of subjects conscious of the ninth letter was 0%. When differentiating the industrial workers from the students, the result was 6% success for workers (age range: 25-50 yo.) and 50% success for students (age range: 9-14 yo.). Among the workers, no particular profession or academic background characterized those who succeeded.

While performing the task, observations allowed us to see the strength of the SET. These are relevant examples extracted from the previous study (Fauquet-Alekhine & Boucherand, 2012):

- Example 1: Some subjects (less than 10 cases) fitted the mask for all the boards by raising the mask several times to see the letters under the mask. Most of them were looking for the letters matching in the windows. They did not notice letter #9 although it is perfectly visible when you are aware of it.
- Example 2: One subject came to the board #5 (where is the trap), put the mask on, counted the letters, and had a doubt concerning the last letter that appeared on the right of the line #1. It was a 'b'. He removed the mask, took the ruler and measured letter #9 which was an 'o', put back the mask, recounted the letters and did not notice that the last window of line #1 was a 'b' and not an 'o'. (subject EMT01)
- Example 3: One subject chose to align the mask on the right column of the lines: for each board, he put the mask adjusting the right-hand windows on the right-hand column of the letters, column #8. Came the board #5: he did the same, and aligned the right-hand windows of the mask on the right-hand column of letters, here column #9. This produced a visible shift for the experimenter-observer as the mask could be seen to have gone over the right edge of the board. But the subject noticed nothing and therefore dealt with letter #9 but could not manage letter #1 hidden by the mask (in statistics, this case is registered as having not dealt with the letter #9). (subject EMT04)
- Example 4: Four subjects performed an initial control which led to accepting the mask using only the middle line windows. Their goal was to work with a dedicated tool (which works fast) but also reliable: considering then that the opening of the top and the bottom window lines of the mask were too large, they applied the mask on the boards shifting the middle window line on each line of the board. Doing so, when they came to board #5, letter #9 of lines #3 and #1 became visible, offset from the windows of the mask (subjects CEM09, P02, P04, TP08 (line 1)) (Figure 3).
- Example 5: One subject took the Letter-test in a room, facing a window, and decided to raise the mask holding the boards vertically. A posteriori, it was verified that letters #9 of the board #5 were

slightly visible despite being covered by the mask. However, the subject did not see them. (subject SSJ06).

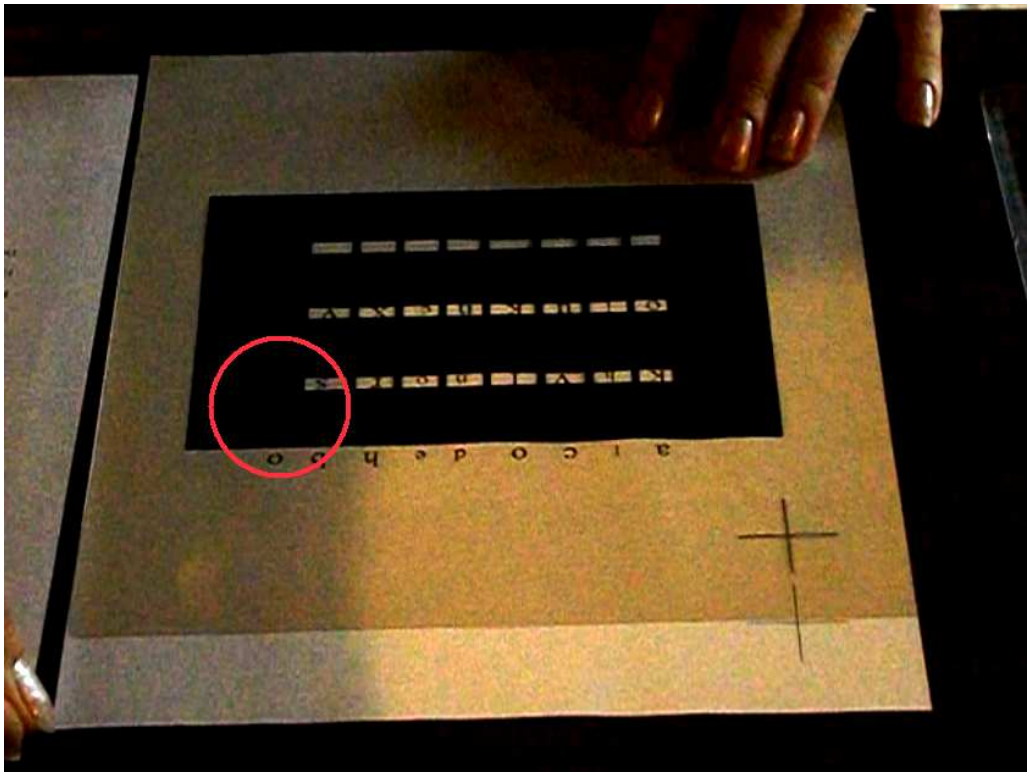

Figure 3: Example of subject shifting the mask when using only the middle line. The ninth letter of the first line is circled in red and clearly appears as belonging to the ninth column. Despite the fact that it is obvious for the researcher, the subject did not notice it in all the cases observed.

The conclusion of these experiments was that no specific professional experience or academic background could help the workers to avoid the powerful Structuring Effect of Tools because it was precisely the professional and academic training that had formatted them and caused them to be subjected to this effect. A possible solution was to break the effect whilst performing the task.

After these experiments, two questions were raised and led to additional investigations. First was that most of the subjects trusted the researcher regarding the reliability of the mask when the test was introduced to them suggesting the mask as a tool designed specifically for the task (reminding us of the famous obedience to authority highlighted by Milgram, 1973, 1974): very few made control measurements of the window size while the first and

last rows could be assessed as not conform depending on the accuracy of the controlling measurements. Second, the "one-by-one" condition of the Letter-test did not allow the subjects to perform an overall control of their activity, though it is required and demonstrated as an efficient tool in their daily job (Fauquet-Alekhine, 2012b). Therefore, two conditions were implemented in the frame of the Letter-test described in the following "Method" section.

2. METHOD

2.1. Design

The Letter-test was fully described in the previous paper (Fauquet-Alekhine & Boucherand, 2012) and briefly in section 1.2. Subjects were asked to individually take the Letter-test with a time limit consisting in counting the letters which height was less or equal to 5 mm on five boards, each board made up of 3 lines of letters (Figure 1). For this purpose, the subjects were given two different tools (the classic ruler or a mask presented as specifically designed for the task in Figure 2) and they had to choose one of them before beginning the test even though they could switch tools during the activity. The experiments were undertaken in each subject's personal office. The test being timed, time-pressure was low to moderate (see appendix).

The previous study was conducted with one condition, the "one-by-one" condition. During this experiment, subjects checked the board of letters one after another. They were not allowed to watch again the boards already checked. It was enriched in the present study with two other conditions.

The first additional experimental condition was the "prior warning" condition. As written in section 1.2, observations showed how much the subjects trusted the researcher responsible for the test. In order to break down this trust and to create an opposite feeling, one of the researchers repeated on the phone exactly the same sentence to each subject just before the test: "Soon my colleague will come to see you and suggest you take a test. Be careful, there is a trap. I won't tell you more, just be careful." Then the subjects took the Letter-test alone with the other researcher as per for the "one-by-one" condition. The dependent variable was awareness and the independent variable was performance.

The second additional experimental condition was the "final control" condition. Subjects were presented with the Letter-test as for the "one-by-one" condition and were warned about the mandatory overall control of the activity they had to perform at the end of the activity. For this aim, after the "one-by-one" step, they were given back all the boards for them to perform the final control as they wanted. As in previous experiments, the test was

taken individually and presented to be done under time-pressure. The assessment of the performance was carried out as it had been for the previous study: success was validated when the ninth letter was dealt with and all counts were right. The dependent variable was final control and the independent variable was performance.

In order to understand mechanisms underlying the SET, results of the Letter-test were used as well as observations of subjects taking the test and their interviews after the test. These materials were combined with observations, interviews and analyses related to industrial events of real operating situations (Fauquet, 2004, 2005; Fauquet-Alekhine, 2012a). The test was taken facing the researcher which allowed him to observe carefully the subject's attitude and way to perform the task.

These three experimental conditions and the related protocol were approved by the Ethics Committee of the Laboratory for Research in Sciences of Energy.

2.2. Subjects

The study was previously conducted with the so-called "one-by-one" condition (N=57) involving professionals from the French nuclear industry (age range: 25-50 yo.) and students (age range: 9-14 yo.). Such number of participants was necessary to obtain a sufficient number of participants per professional category (thus ensuring a satisfactory representativity of the trades) which was one of the experiment variables. As we found that this variable did not influence the results among the adult population, the additional conditions designed for the present study involved workers (from Chinon NPP too) from the operating trades only, whatever their professions in the French nuclear industry, with 10 participants per experimental condition (N=20; age range: 25-50 yo.; 100% male subjects as women are rarely involved in operational jobs in this industry, their proportion among operational workers intervening on the industrial process being less than 0.5%). The distribution of the subjects per groups gave rise to preliminary statistical calculations in order to verify that a t-test of Student regarding the comparison of the mean performance per group could be relevant. We found that the statistical power would be greater than 0.8 and concluded that 10 participants per additional condition would be enough.

2.3. Procedure

Subjects were met individually in their office and were all volunteers. They were told that results would be analyzed respecting anonymity. For subjects involved in the "prior warning" condition, they received the phone call just before the face-to-face contact. For subjects involved in the "final control" condition, they were told a final

control would be asked of them at the beginning of the experiment. The researcher explained that the objective was to test the efficiency for individual simple task using tools.

The activity of the test, the board and the tools were presented. Subjects were told the activity had to be performed in a minimum of time, individually, the test being timed.

After checking the boards, for "final control" condition, subjects were given back all the boards together and asked to perform a final control as they wanted.

Then the researcher gave the results of the individual performance assessment to the subject, explained the actual objective of the study, asked questions to complete the observations, and answered the subject's questions if any.

3. RESULTS

3.1. Quantitative results

Performance assessment was binary: success or failure. Success was stated when the right number of letters was identified, the size of which was less or equal than 5mm, including letter #9. All participants succeeded in detecting the letters among the eight first ones per line, but less detected letter #9 when expected. The corresponding percentage is given in the first line of table I. In addition, fewer were conscious that the last board presented an additional letter. The corresponding percentage is given in the second line of table I. For example, in the "one-by-one" condition, no subjects were conscious of letter #9 even when detected.

Student t-test comparing values showed a significant differentiation ($p<.001$). Statistical calculations showed that the statistical test power was greater than 0.88 which confirmed the consistency of the data.

Table I: Quantitative comparative results for each experimental conditions of the Letter-test in terms of performance.

	1) one-by-one	2) Prior warning	3) Final control
Deals with letter #9	11%	71%	30%
Deals with letter #9 and aware of the presence of it	0%	43%	20%

Results showed that the best performance was obtained with prior warning inducing a deconstructed condition of confidence between the subject and the researcher. A median performance was obtained in the “final control” condition, but it must be noted that the control was not under time-pressure. In fact, for all of the subjects involved in the “final control” condition, the control phase took more time than the activity itself and for most of them more than twice the time. If efficiency is expressed in terms of performance/time ratio of the task, then the “prior warning” condition was much better than the other conditions.

The ratio between the number of subjects who dealt with the ninth letter and the number of subjects who were conscious of the ninth letter was very close in each condition “prior warning” and “final control”, resp. 60% and 67%. For the “one-by-one” condition, none of the subjects noticed letter #9, whether it was dealt with or not.

3.2. Qualitative results

Regarding the "final control" condition, most of the subjects chose the mask to perform the timed task, and opted for the ruler during the control in a redundancy approach.

Observations of subjects taking the Letter-test as well as their interviews after the test, combined with observations, interviews and analyses related to industrial events of real operating situations (Fauquet, 2004, 2005; Fauquet-Alekhine, 2012a), allowed us to identify major characteristics of the SET.

As for the “one-by-one” condition presented in section 1.2, observations made during the realization of “prior warning” and “final control” conditions showed how the tool structured the activity and seemed to focus attention on certain informative clues, thus helping to achieve the goal, and shadowing peripheral information.

When the Letter-test was presented to the subjects for the "one-by-one" condition, subjects asked several questions to be sure they understood what they had to do correctly. Some of them repeated what they had understood of the task before performing it.

Two behaviors were observed:

- Subjects immediately trusted the researcher and accepted the mask and ruler as reliable.
- Subjects undertook a verification of the mask before performing the task: some of them took the ruler and measured the window height on the mask either randomly, or for all of them; others applied the mask on the board #1 to verify the match.

Very few subjects decided to use the ruler without verification.

Depending on their findings once they had verified, subjects used the mask or a part of the mask (see example #4, section 1.2). Interviews showed that the mask was preferred as an industrial tool allowing to perform the task faster, and that their concern regarding time-pressure was salient for the industry professionals (adult subjects) whereas it was of secondary order for the students. After the test, adult subjects explained that they preferred using a dedicated tool to perform a task.

For the subjects who did not apply any control before the task, they explained after the test that they trusted the tool as it was presented as dedicated to the task, designed for it.

While performing the task of the Letter-test, some subjects had doubts and implemented strategies to ensure the correctness of their work (see examples #1 to 5, section 1.2). Several subjects behaved as in the example #2 for other boards except the fifth one. They are not mentioned in the examples of section 1.2. Nevertheless, very few of them applied a control throughout the test: most of the time, awareness was visible at the beginning of the test, for the two first boards, and, afterwards, subjects performed the task in a routine manner. For these subjects who did not apply any control at the beginning of the test, performing the task in a routine manner came very early.

When the Letter-test was presented to the subjects for the "prior warning" condition, subjects showed having doubt throughout the test. Preliminary measurement of the windows of the mask was systematic in a more or less efficient manner but every imprecise measurement led to the mask being taken away and to the use of the ruler: nobody decided to use just the middle line of the mask. Interviews of the subjects showed that they were constantly looking for a trap. It is the only condition for which subjects did not seem to engage themselves in a routine task.

In the case of the "final control", the quality of the control carried out at the beginning of the test appeared to be similar to the one occurring for the "one-by-one" condition and then subjects engaged themselves in a routine task. As the final control was not timed, the control lasted longer than the identification of the letters (the task itself).

Regarding the examples presented in section 1.2, observations showed that the subjects did not see letter #9 while adopting behavior or method that made the ninth letter visible; this was clearly seen by an informed observer such as the researcher. During the interviews that followed, subjects explained that they did not see anything suspicious while performing the task, but they could not explain why.

All subjects confessed that time-pressure was an important factor in that it orientated their choice for the tool used to perform the task and made them center their attention to the relevant factors useful to achieving their

goal. This was different for most of the students who explained that the main point was to control what they had to do; in this objective, working with the ruler at the beginning or later during the activity was the more appropriate choice.

4. DISCUSSION

The discussion takes two directions: one concerns the performance, and one concerns the psycho-cognitive aspect of the Structuring Effect of Tools (SET).

4.1. Successful solutions for better performance when submitted to the SET

As reported in sections 1-2 and 3-2, the industrial worker categories were less successful when dealing with the ninth letter compared to the student category. Studies undertaken on diversifying experience and power of hierarchy may give elements of explanation. Ritter et al. (2012) showed that "a diversifying experience - defined as the active (but not vicarious) involvement in an unusual event - increased cognitive flexibility more than active (or vicarious) involvement in normal experiences" (p. 961). In the light of this conclusion and considering work in a nuclear power plant context, the Letter-test was considered as a "normal experience" as it looked like a common task in terms of protocol: use of an industrial tool to perform a routine task made up of taking measurements under low or moderate time-pressure. The flexibility common to any form of acquiring information (Dinet et al., 2012) seemed to be effective only at the beginning of the cognitive process summoned during the activity. Thus the Letter-test did not offer conditions favoring creativity through cognitive flexibility. Furthermore, considering nuclear power plants' social organization, power of hierarchy is characterized by its strength and its stability. According to Slitge et al.'s findings (2011), this does not favor flexible thinkers and may also contribute to understanding why the industrial categories were trapped in a structuring effect. Yet, the effect of the subjects' possible negative perception of inattention at work was investigated. According to recent studies (Pecher et al., 2011), this might alter the ability to process relevant information from the environment.

As can be clearly seen on Table 1, the best performance was obtained in the "prior warning" condition. This prior warning engaged the subjects i) in a prior control of the task, ii) in an awareness during the realization of the activity possible due to the relative short duration of the task (less than 10 mn.). Transposing this "prior warning" condition to the world of work, this might correspond to the necessity of absence of confidence between the co-workers and the necessity to systematically verify everything everywhere. Obviously, this is not possible.

Systematically verifying everything everywhere is cognitively of high cost and workers would not be able to stand it for a task lasting several tens of minutes or more. In parallel, analyses of work activities showed that confidence between co-workers is a necessity for good occupational health, "relationships based on trust and shared values" are needed (ACAS, 2011, p. 3); "mistrust is positively correlated with high role ambiguity, which leads to […] psychological strain in the form of low job satisfaction, decreased well-being and a feeling of being threatened by one's superior and colleagues" (Sauter et al., 2012; see also Kahn et al. 1964; French & Caplan 1973). Therefore, it is not possible for the management of high risk industries to request permanent defiance towards their colleagues at the expense of their mental health.

Yet, we may consider what would induce the same behavior without this defiance. Observations of the subjects in action showed that this behavior corresponded in fact to the implementation of a prior control followed by constant vigilance. On French nuclear plants, Human Performance tools have been required for several years (Fauquet, 2007; Theurier, 2010; Fauquet-Alekhine, 2010, 2012a; Fauquet-Alekhine et al., 2012). Among them, the "Take a minute" is a professional practice which takes place at the workplace just before the activity starts; it asks workers to take a minute out of urgency of the situation to analyze the work environment: Am I on the right unit? The right track? Using the right equipment? Is there a risk of accident? … The "Take a Minute" is also used in case of interruptions or progressive drift of the working situations outside the planned framework (Fauquet-Alekhine, 2012a). This practice may be considered as the prior control defined here for the experimental "prior warning" condition. Then the question of the implementation of constant vigilance which has a high cognitive cost remains unanswered. If such vigilance is not continuously possible, this means that the performance obtained in the "prior warning" condition cannot be attained in real operating situations if only based on similar effects induced by "prior warning", i.e. defiance.

Regarding the "final control" condition, as seen on Table 1, the performance was not as good as for the "prior control" condition, but much better nevertheless than for the "one-by-one" condition. We can then reasonably assume that the combination of the "Take a Minute" practice with the final control could help to raise the performance to a intermediate level between what is obtained in the "prior control" and the "final control" conditions.

4.2. Conceptualization of the SET

Before a conceptualizing analysis of the SET, a question must be answered. We highlighted the negative contribution of the SET with our experiments. What about the positive contribution of the SET? Considering the Letter-test trap, failures occurred because the object of the work activity (the boards) was different from what was expected for a reliable application of the tool and because this was not detected by the subjects. This object did not conform to expectations. The same difficulty would occur if the tool had not conformed to its expected state. Thus the SET has a negative effect and leads to a failure if there is a lack of correspondence between the real tool and the expected tool or between the real object of work and the expected object of work. On the contrary, in case of compliance between the real tool and the expected tool AND between the real object of work and the expected object of work, then the SET may lead to a successful outcome and good performance including a high level of efficiency (less time to perform the task with reliability). In these conditions, the SET offers a great dilemma to the organizational decision-maker: Where must the resource be reinforced (reliability of tools, of organization, of workers' practices) to avoid the negative effect of the SET? Is it worth engaging such efforts to reduce or avoid the negative effect occurrence if this is extremely negligible compared to the positive effect? These are questions for another study. Nevertheless, we may assume that dealing with the negative effect raises a real challenge should it have significant consequences on safety despite negligible production consequences.

Having established the possible positive/negative contribution of the SET, we aim at identifying the mechanisms underlying the phenomenon.

According to the observations, interviews and analyses related to the Letter-test and to industrial events of real operating situations (Fauquet, 2004, 2005; Fauquet-Alekhine, 2012a), let us first analyze the SET in the light of theoretical considerations already studied and described elsewhere. This step is important as we postulate that the SET is not a simple psycho-cognitive process, but a complex process likely combining several basic processes that must be identified.

4.2.1. Anchoring/Adjustment

The Anchoring/Adjustment effect (Tversky & Kahneman, 1974; Oppenheimer et al., 2008; Thomas et al. 2003) combines on one hand an initial assessment of the situation and its outcomes, and on the other hand adjustments according to incoming information to reach this assessment. With the SET, when an initial assessment was observed at the beginning of the activity which effectively looked like an anchoring point, following

adjustments were not made; on the contrary, it seemed that incoming new information was difficult to be wholly perceived.

4.2.2. Attentional control, Focusing effect and SOF-based attention

As reported in section 3.2, time-pressure was an important factor which made the subjects centering their attention to the relevant factors useful in achieving their goal (Krueger & Funder, 2004). This may refer to attentional control (Astle & Scerif, 2009) also named endogenous attention or endogenous attentional selectivity (Mayr et al., 2014; Theeuwes, 1991). This psycho-cognitive process supposes the subject is choosing where the attention will be focused and what will be left aside during the activity. Reformulating Wass et al. (2012) following Ruff & Rothbart (1996) and Scerif (2010), attentional control is the subjects' ability to regulate and to direct attention, being able to actively guide their attention towards the chosen informative data. People may be trained to increase their capacities for attentional control (Chiappe et al., 2013; Goode et al., 2013).

In our study, observations and interviews of subjects showed that, during their activity, they were involved in an attentional control process with a special focus of attention helping them to be more efficient.

This may refer to a Focusing effect defined as a cognitive bias due to the high importance given by the subject to specific aspects of the situation they live (Schkade & Kahneman, 1998; Kahneman et al., 2006). This effect is greater when subjects are under low or moderate time-pressure as demonstrated by a well-known experiment of pro-social behavior conducted by Darley and Batson (1973): they asked students individually to hurry from one building to another "while in transit, the subject passed a slumped 'victim' planted in an alleyway." They showed that the proportion of subjects "who offered aid" decreased significantly with increasing time-pressure and concluded that this could be due in part to the fact that, under time-pressure, subjects had a tendency to narrow the cognitive map, referring to Tolman (1948) and meaning that subjects had thus reduced the cognitive possibility to seize informative data not directly linked to their current goal. Subjects were centered on relevant and central informative data which were necessary to find the way and reach the next building.

This perfectly matches what the subjects of our experiment explained they were doing during the Letter-test. This also matches the narratives given by the workers during interviews following their involvement in the occurrence of a safety event (see examples #B and C, section 1.1).

Yet, this attentional process always appears to be linked with visual attention as the informative data needed to perform a task is visual for a great part in industrial context and exclusively visual during the Letter-test. During the Letter-test, we observed that subject's visual attention seemed uniformly distributed at the beginning of the activity for an overall appreciation of the situation while in parallel processing the acquired information. During this first stage, subjects asked a lot of questions concerning the task. Then in a second stage, while performing the task, the subjects' visual attention remained limited to a specific area of the situation or specific details of the activity. In line with the model proposed by Eriksen & St James (1986) enriched by Castiello & Umilta (1990), stages one and two refer to a zoom-lens effect. The model postulates that attentional resources are limited. We can speak of the "limited information-processing capability" of humans (Schultz & Searleman, 1998; Caldwell, 2008). Therefore, to be more efficient whilst performing the task, subjects reduce the focus of attention in order to increase the amount of attentional resource to central informative data at the expense of peripheral informative data (Adamo et al., 2008), a psycho-cognitive process observed under sustained attention. Examples #1 to #5 presented in section 1.2 illustrate well this effect during the Letter-test.

However, the attentional process may be oriented not only by focusing on a selected area of the space: "the unit of attentional selection may also be based on features and objects, in addition to space" (Chen, 2012, p. 784). Different aspects of attention are therefore to be envisaged: space-based attentional control, object-based attentional control and feature-based attentional control (Duncan, 1984; Liu et al., 2003; Chen, 2012) condensed in this section title as SOF-based attention. We cannot go further in our analysis of such phenomena as neither the Letter-test nor the safety event conditions were instrumented to investigate these aspects of the SET. Nevertheless, it can be assumed that all of them may be concerned by the SET and the predominance of one of the SOF-based attention aspects over another depends on the context of the activity including the subject's characteristics. This assumption was developed through observation of subjects taking the Letter-test and actually focusing on visual clues. This would not have been the case of an activity favoring audio clues at the expense of visual ones. More importantly, we assume that the SET does not remain at the level of the subject's perceptive cognition (as for the SOF-based attention aspects) but concerns a higher level of cognition with other parameters coming into account such as exposure duration, salience of configuration, object representation (Shomstein & Yantis, 2004; Shomstein & Behrmann, 2008), all factors that contribute to assign the attentional priority and that make attentional control a

highly complex phenomenon. This means that the conceptualization of the SET requires another level of description of attentional control. The assumption that the SET could address a higher level of the subject's cognition is discussed in next section.

4.2.3. Functional Fixedness or Initial Goal Fixedness: a higher level of cognition for the SET

The main role played by the tool in the Letter-test and in the industrial events we studied suggested a link with Functional Fixedness related to affordance (Railen, 2015, p. 22). This psychological process makes the subjects focus on the functional purpose of the tool. According to Arnon & Kreitler (1984), Functional Fixedness consists in "focusing on some function of an object while overlooking another necessary for problem solving" (p. 11). This process was clearly highlighted by the well known candle experiment of Duncker (1945) showing that when subjects are presented both an object and its functional purpose in a given activity context (Kearsley, 1975), the extrapolation towards another functional purpose for the object by the subjects is not trivial.

In literature, Functional Fixedness is studied to understand the way subjects are able or not to enhance or transform the purpose of a tool as it is a priori suggested by its functional design or by its functional presentation. The research question is: Will the subject be able to perform task A using a tool designed and presented to perform task B?

Regarding the SET occurring during the Letter-test, the question may be formulated slightly differently: Will the subject be able to perform a task concerning object B using or adapting a tool designed and presented to perform the same task concerning object A while object B is expected by the subject?

As we can see, the problem encountered in the Letter-test is somewhat different from Functional Fixedness. Here, the subject did not just focus on the functional purpose of the tool but on factors at the beginning of the cognitive dynamic process that created the relationship subject'mind-tool-object whilst engaging in the task. This dynamic process is the mental activity related to the task. According to the Activity Theory, to perform the task, there must be the emergence of a system of coordinated actions which is possible if there is a "move from a conscious goal to a conceived condition of action" in the subject's mind (should we rather call it “preconceived” as it happens before action) and, at this stage of the process of activity, the "levels of awareness" appear (Leontiev, AA., 2001/2006). In the studied condition named "one-by-one", the preconceived condition of action was elaborated for expected object B while object A was presented: the preconceived condition of action was not adapted when object

A was presented since not detected and considered like object B. The question is: What made them consider object A like object B? Or should we ask: What made them not consider object A like object A?

Observations and interviews showed that subjects were focusing on factors of what the action was directed towards at the beginning of the activity: this was the initial goal. This means they were focusing on the characteristics of the initial goal. They were unable to reconsider the preconceived condition of action since the conscious initial goal did not change. The fixedness phenomenon concerned characteristics of the initial goal: Initial Goal Fixedness.

Yet, the effect of Initial Goal Fixedness was lessened in the Letter-test for the "prior warning" condition and for the "final control" condition. What happened? As previously mentioned, levels of awareness appear when a conscious goal moved towards a preconceived condition of action; if then the conscious goal was not then reconsidered, the preconceived condition of action remained unchanged. Therefore, the associated levels of awareness do not change. Awareness is bounded when nothing helps reconsider the initial conscious goal. We recognize here the characteristics of bounded rationality introduced by Simon (1982): subjects work with limited information according to what is available; subjects process this information according to their own capacity which may further reduce the amount of information taken into account; these characteristics are even more limited under time-pressure.

So, what makes subjects "reconsider" Initial Goal Fixedness in the experimental conditions of "prior warning" and "final control"?

In the "final control" condition, due to the nature of the experiment, the initial conscious goal was reconsidered most of the time since the mandatory final control aimed at making subjects approach the task differently from the first trial. Therefore, levels of awareness changed, reducing the effect of bounded awareness, and helped subjects to discover the mistake regarding the last board.

The explanation is less simple in the "prior warning" condition. Yet, considering that bounded awareness is associated with bounded preconceived condition of action, and considering that action may be subdivided into operations, themselves subdivided into functional blocs (Zinchenko & Gordon, 1976; Leontiev, AA., 2001/2006), we may suggest that Initial Goal Fixedness is linked with selected functional blocs. In condition of "prior warning", we may assume that the selection of functional blocks made by subjects was much wider than in the "one-by-one" condition, enabling them to be aware of the experimental trap by impeding the anchoring of the initial goal.

4.2.4. Einstellung effect

In our study cases, subjects were involved in an activity to reach a goal designed by or for the task. In section 4.2.2 we saw how this process was reinforced by time-pressure favoring the installation of the attentional control process and Initial Goal Fixedness. Yet another specificity of the activity was observed on both experimental and industrial cases: the routine character of the task. The aforementioned prior anchor may well be sustained by the repeated character of the task. This leads us to consider the SET in the scope of the Einstellung effect illustrated by Luchins' water jar experiment (Luchins, 1942), also called "mental set" (Bilalić et al., 2008a & b; Dunn, 1972; Kirwan, 1992; Schultz & Searleman, 1998; Bilali? etal. 2008). The Einstellung effect refers to the subject's disposition to perform a task in a given way even though another manner could be more suitable.

In the case of the Letter-test, the repeated character of the task was induced by applying the tool consecutively on five boards and observations showed at least in the "one-by-one" and in the "final control" conditions, that the activity seemed to become familiar to the subjects very early with expected outcomes (Woltz et al., 2000) reinforced by time pressure as demonstrated before (Schultz & Searleman, 1998). It remained the same for industrial events: narratives produced by the workers emphasized the routine aspect of their task and this was pointed out during the event analysis as a factor contributing to the unexpected outcome. The routine character of the task favored the way workers chose to perform the task through a patterned scheme of actions and inhibited their capacity to identify its non-appropriateness regarding the task. Therefore, the Einstellung effect appeared as a process contributing to maintaining the patterned scheme of actions from the point of anchor. In the “prior warning condition, subjects’ permanent vigilance prevented the Einstellung effect being effective.

4.3. Applicative perspectives

The conceptualization of the SET understood through the IGF brings new perspective of improvement for high risk industrial operation. By suggesting considering deviation from expected results as a possible contribution of the SET and/or IGF, event analysis may gain in efficiency. If SET and IGF are effectively identified as factors contributing to event occurrence, corrective actions will gain in relevancy. To illustrate this perspective, let us consider what was undertaken after events reported above. Examples #A and B gave rise to typical corrective actions: the management requested the used of reliable practices (Fauquet-Alekhine, 2012a) and reaffirmed the need of procedure adherence. These actions cannot cope with SET or IGF and they increase the workers’ stress by

making them think that events just result of personal contributions. Example #C gave rise to a reinforcement of the control process making it more heavy for controllers (more documents to check) and overloading the organization (more controlling steps), both contributing to the emergence of a paradoxical new risk: reducing the control efficiency (too much control kills the control). Analyzing events of examples A to C with a SET or IGF approach would help for instance to reconsider the tool, the way and the context in which it is used, dealing thus with the actual cause of the events by helping the workers instead of stressing them with common managerial injunctions.

However the solution(s) to the SET and IGF remain to be found as operating events were never considered from this standpoint. The results showing that the "prior warning" condition gave better performance cannot be a solution as it is not possible for the management of high risk industries to request workers' permanent defiance towards their colleagues, tools or equipment at the expense of their mental health (§ 4.1).

Undertaking additional studies to cope with this problem might be a benefit not only for nuclear industries. Indeed other high risk industries might be concerned as potentially submitted to the SET, fulfilling the occurrence conditions listed in section 1.1 for some tasks. For example, aircraft pilots are used to applying short check-lists for flight operations before the flight in a routine manner (Fauquet-Alekhine & Labrucherie, 2012); anesthetists (Fauquet-Alekhine et al., 2014) face routine situations such as making products injections prepared in advance by nurses.

5. CONCLUSION

The Structuring Effect of Tools (SET) was identified during work activities related to nuclear reactor operation in particular conditions: The SET was observed for familiar simple tasks under low or moderate time pressure related to a task for which the importance did not make it an emergency, leading subjects to focus their attentional control; The SET was observed when subjects were individually involved in one activity, were experienced regarding the proposed task, were perceived as conscientious by the experimenters, could explain exactly what they had to do during the activity afterwards, claimed afterwards they knew what to do when they performed this activity, were not distracted during their activity, were not stressed as there were no high stakes concerning their task and were submitted to low to moderate time pressure. In terms of Rasmussen's SRK model, subjects were engaged in routine activities. These conditions favored the isolation of the SET for identification and

study; yet it does not presume any other possible contexts in which the SET could be observed in combination with other factors but in which it would be less easy to identify the SET.

The studies here undertaken, reproducing conditions of occurrence of the SET in experiments, helped us to suggest a description of the SET according to the following three proposals (§4.2):

- The positive aspect: the subject is able to perform a task concerning object A using a tool designed and presented to perform the task concerning object A efficiently.
- The object-based negative aspect: the subject is unable to perform a task concerning object A using or adapting a tool designed and presented to perform the same task concerning object B when object A is expected by the subject.
- The tool-based negative aspect: the subject is unable to perform a task concerning object A using or adapting a tool designed and presented to perform the same task concerning object A when the tool is designed and presented for object B.

The SET is either positive or negative when certain factors are combined. The positive aspect is reached in case of compliance between the real tool (the one used) and the expected tool AND between the real object of work (which the tool is applied to) and the expected object of work. If one of these two conditions does not match, then the negative aspect may predominate.

The three proposals above describe three aspects of the SET:

- The positive aspect is congruence between object, tool and the mental representation the subject has of them.
- The object-based negative aspect occurs when there is a shift between the object and the representation the subject has of it.
- The tool-based negative aspect occurs when there is a shift between the tool and the representation the subject has of it.

The psycho-cognitive process which underlies the Structuring Effect of Tools was here identified as Initial Goal Fixedness (§4.2.3). Initial Goal Fixedness during work activity is constituted of several steps:

- an initial goal anchor inducing a preconceived condition of action to perform the task,

- a focus on the characteristics of the initial goal of the activity favored by the Einstellung effect whilst performing the task under low or moderate time-pressure.

The anchoring point is elaborated by subjects when they are about to perform the task. It is due to a prior assessment of the situation and its outcomes whilst apprehending the task. This anchor occurs at the very beginning of the activity.

The focus is elaborated so as to be more efficient: subjects reduce the scope of the informative data due to human's limited information-processing capability. This is achieved through an Attentional Control process.

The combination of focus and the Einstellung effect prevents the subjects from reconsidering the initial goal of the activity and the induced preconceived condition of action to perform the task, thus reducing awareness. Initial Goal Fixedness is related to cognitive map narrowing and to bounded rationality.
Initial Goal Fixedness is favored by sustained attention and time-pressure and probably depends on the subjects' cognitive capacity as it is linked with the limited information-processing capability (which differs from one individual to another).

Our experiments have shown that Initial Goal Fixedness (IGF) may be avoided or inhibited. Avoided through awareness should awareness remain active (the "prior warning" condition) and inhibited when subjects are forced to reconsider the preconceived condition of action to perform the task and thus the initial goal of the activity. The point is here to impede anchoring of the Initial Goal Fixedness and prevent the Einstellung effect. However, as discussed in section 4.3, further studies are needed to identify appropriate solutions without jeopardizing workers' health.

These findings and results were obtained in the framework of nuclear industries but may not be limited to this domain. Examples of how other high risk industries might be concerned are given in section 4.3. This makes the SET and the IGF, their understanding and their coping, a challenge of great interest with safety, production stakes and therefore financial concerns. In addition, Structuring Effect of Tools underpinned by Initial Goal Fixedness is facing an exciting dilemma. Indeed it would be interesting for industrials to cope with the negative aspect of the SET in order to avoid deviations and improve performance (our experiments demonstrated a possible very significant gain), but this might go against the purpose of the tools that precisely favor workers' efficiency by

enhancing the features that also favor the negative aspect of the SET. This point might become a huge difficulty when considering the findings that could be interpreted as suggesting coping with it by increasing subjects' awareness: awareness cannot be permanent due to human cognitive capacities and mental health considerations. Here the conceptualization of the SET may help: it showed that, more than a question of maintaining awareness, the solution seems to lie in impeding Initial Goal Fixedness. This consideration might open new fields of research both in Psychology and Neuroscience.

APPENDIX

Three-level scale regarding time pressure

This scale was elaborated on the basis the analysis of 200 safety events on the NPP of Chinon over the past ten years (interviews with actors of the event, causal analysis of the event and factors of comprehension for each cause, validation of the analysis with actors) and observations of real operating situations (Fauquet, 2006; Fauquet-Alekhine & Boucherand, 2011). The results led to 7 objective criteria describing time pressure applying to workers in control rooms or in the field (independently from any other factors such as the activity stake). These criteria were then associated to a three-level scale characterizing time pressure for these kinds of activities: low, moderate and high.

Table A.I. Criteria associated to a three-level scale characterizing time pressure.

levels	**criteria**
low	Subject has all the time needed to perform the activity
moderate	Subject works within flexible time limits which are coherent (longer) with the time needed to perform the activity
moderate	Subject works within fixed time limits which are coherent (longer) with the time needed to perform the activity
high	Subject works within fixed time limits which correspond to just the time needed to perform the activity
high	Subject works within time limits which are shorter than the time needed to perform the activity
high	Subject must work in the shortest time possible because of emergency

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CONFLICT OF INTEREST

The authors declare no conflict of interest in relation to this article.

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