Learner’s Activity During the Understanding of an Interactive Animated Mechanical System: Eye Tracking Investigation

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ABSTRACT
In two experiments we examined how learners understand an animation about a mechanical complex three pulleys system. In the first experiment we tested the animation user-control and the orientation of the attention of the learners. The second experiment tested the potential effect of adding signaling cues like arrows on the comprehension of the mechanical device. In the two experimental designs eye tracking was registered before a comprehension test. The first experiment showed a positive effect of a full controllable animation and also of a verbal explicit orientation of attention on the understanding of the pulley system. The eye tracking data indicated that the learners process strongly the areas of the animations where a great amount of motion is involved along the causal chain of events. The second experiment did not show any effect of adding implicit signaling cues.

1. Introduction

The growth of technology produces a large variety of multimedia animations in learning and education areas. But, the cognitive benefits of animated illustrations for a best comprehension of technical or scientific documents stay still hypothetical [1]. Some of the researches show a positive effect of animation in complex system comprehension [2], but many others show no effect or a negative effect [3]. An interesting explanation for the lack of cognitive benefits of animations appear to be the frequent violation of the apprehension principle defined by [1]: “the structure and content of the external representation should be readily and accurately perceived and comprehended” (p. 256).

In the experiments presented in this paper, we test two possible ways to increase the apprehendability of an animated mechanical system. The first possibility relies on the level of interactivity with the course of the animation, the second is related to the orientation of learner’s attention, by a precise specification of the task during the animation processing or by adding signalling cues like arrows on the animation.

1.1. User-control of the animation

Previous research explored the “principle of interactivity” [4] by studying learner-control on the animation. Among these researches, some results show a benefit of interactive presentation [5]. However, a high level of interactivity is not always a powerful condition of presentation. Another body of researches shows that full interactivity is not effective for learners with little prior knowledge about complex systems [6].

1.2. Attentional orientation

Another way to enhance the apprehension of animations could be to focus the orientation of learner’s attention on specific information. This focus can be supported by explicit verbal instructions or by implicit signaling cues like arrows for example.

1.3. Off-line and on-line measures of cognitive processing during comprehension

The great majority of research about multimedia comprehension used off line written questionnaire to measure the comprehension performances. At this time, we ignore the nature of the on-line cognitive processing of animations. In the experiment presented below we measure the on-line processing of animations of the three pulleys system-using eye tracking technique, followed by comprehension measures. We expect that interactivity features and specific orientation of the learner attention will conduct to different eye tracking patterns.

1.4. Experimental overview

In the first experiment, we study three different levels of interactivity during the understanding a three pulleys system diagram by adult’s participants (figure 1). The levels of interactivity considered consist in different user control possibilities upon the course of the dynamic simulation of the functioning of the three pulleys system. For each level of control, we specified four different levels of task specification. The goal of this task specification was to direct the attention of the
learner on specific diagram features during the study time of the animated system. In the second experiment we study the effect of the presence of arrows in the three pulleys system diagram for two-presentation format: static or animated. In both experiments two groups of subjects were always contrasted: one with high spatial abilities and the other with low spatial abilities.

In these studies, eye movements are captured during the presentation of the animation. Several eye movement indicators were used. The first eye data indicator was the number of fixation in different area of interest (AOI). The second eye data indicator was the number of transitions between the AOI.

2. Experiment 1

2.1. Method

2.1.1. Subjects. One hundred and twenty one undergraduate students from the University of Burgundy participated.

2.1.2. Individual difference measure. We measured mechanical and spatial abilities of each participant with a French abbreviated form of DAT, Differential Aptitude Tests.

2.1.3. Experimental task materials. The material used in this study was adapted from Hegarty’s experiment [7] and consisted of an animated three-pulley system (figure 1). We used three versions related to the three levels of user control. The subjects were presented with a non-controllable animation, or a partially controllable animation, or finally, a fully controllable animation.

The non-controllable version consisted in an animated diagram of the pulley system. Animation started when the subjects clicked with the mouse in the diagram area. In the partially controllable version, the course of this animation was controllable sequence by sequence (five short animated states) when the subjects clicked with the mouse in the diagram area: one click, one sequence. Subjects could repeat the animation when all the sequences were finished. In the fully controllable version, the learners could manipulate the system, as they wanted by pulling on the end of the free rope, after they have clicked on the end of the high rope.

2.1.4. Memorisation and comprehension measures. After the study stage, subjects were tested with comprehension questions. Three types of questions were elaborated. The first series of questions concerned the configuration of the elements of the pulleys system. The second concerned the local kinematics of the system. The third concerned the entire functional mental model of the system. We determined three comprehension sub-scores for each type of questions.

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Figure 1. The three pulleys system no pulled and Areas of interest used to analyze the eye fixations
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2.1.5. Apparatus. The stimulus was presented on a computer screen. The eye fixations of the subjects were monitored by an ASL (5000) corneal reflectance and pupil-centre eye trackers, combined with a magnetic head tracker, and were recorded with gaze tracker software. ASL 5000 is a 50-hertz system recording the position of the subject’s gaze every 20 millisecond.

2.1.6. Procedure. In a first stage, the mechanical and spatial abilities were measured collectively with the differential aptitude test. This, then, allowed two groups of participants to be identified: subjects with high and low mechanical and spatial abilities. Sixty high and sixty-one low mechanical and spatial abilities constituted the two contrasted groups. The subjects were then equally distributed among the three type of control and the four level of task specification. The validity of the distribution was tested with Newman-Keuls tests.

During a second stage, subjects were presented with one of the three versions of the animated pulley system. During the study period of the device, eye movements were registered. According to his or her specific task the goal assigned to each participant was to understand the operating system. The subjects were informed that they had to use the animation at least three times.

After this stage, subjects answered the comprehension questions test in a booklet.

2.2. Results

2.2.1. Comprehension performance. The learners with high spatial and mechanical abilities performed better than the learner with low abilities, F(1, 97) = 21.91, p < .0001. The learners with a fully controllable animated diagram performed slightly better than the learner with no controllable or partial controllable animated diagrams, F(2, 97) = 2.97, p = .056. The learners with a specific orientation of attention upon the functional model and, to a lesser extent, with local kinematics
performed better than the learners with a specific orientation on the configuration elements or with no orientation of attention, $F(3, 97) = 4.47, p < .01$. Moreover, the effect of the comprehension indicators is significant: the scores of configuration are higher than the scores of kinematics which are higher than the scores obtained for the functional model, $F(2, 194) = 555.54$, $p < .0001$. The interaction between spatial ability levels and the three indicators of comprehension is significant, $F(2, 194) = 5.81, p < .01$. This interaction indicates that the learners with high spatial abilities performed better than the learners with low spatial abilities only for the kinematics and functional model questions. The interaction between the task type and the three indicators of comprehension is also significant, $F(6, 194) = 5.04, p < .001$. This interaction shows a higher benefit when the attention of subjects is focused on the functional model of the system.

2.2.2. Eye tracking measures. In order to assess the on-line processes in the comprehension of animation, we analyzed the eye fixations of one hundred and thirteen subjects. We analysed the number of fixations in every Area of interest (AOI) and the transition between the different AOI. So, we created four specific AOI, marked in figure 1.

2.2.3. Number of fixations. Results showed a significant effect of the control level, $F(2, 89) = 7.08, p = .001$. The number of fixations was more important in the partial control animation than for the full control animation, that was in turn more important than for the no controllable animation. Moreover, the effect of the type of AOI was significant, the number of fixations for the third AOI (area including an important amount of motions) was higher than the first and second AOI and higher than the fourth AOI, $F(3, 267) = 49$, $p<.0001$.

2.2.4. Transition between the AOI. We determined three types of transitions between the different AOI. First, we distinguished the global transitions (transitions between two non-neighbourhood AOI), second, we distinguished the local transitions (transitions between two neighborhoods AOI), finally, we distinguished the “causal chain” transitions (between three neighbourhoods AOI at least).

Results indicated a significant effect of the user-control, $F(2, 89) = 3.80$, $p < .05$. Controllable animation induced more transitions than the no-controllable animation. The number of local transitions was higher than the number of global transitions and this last one was higher than the causal chain transitions, $F(2, 178) = 302.32$, $p < .00001$. Moreover, results showed a significant interaction effect between the different types of transitions and the task type, $F(6, 178) = 2.18$, $p < .05$. This effect indicated that the number of local and causal chain fixations was lower for the configuration task.

2.2.5. Discussion. Results are discussed in the general discussion.

3. Experiment 2

3.1. Method

3.1.1. Subjects. Eighty undergraduate students from the University of Burgundy participated.

3.1.2. Individual difference measure. As in experiment 1, we measured mechanical and spatial abilities with DAT 5.

3.1.3. Experimental task materials. As in experiment 1, we used the three-pulley system. Subjects were presented a static or an animated diagram, including or not arrows representing rotation and direction (figure 2).

3.1.4. Memorization and comprehension measures. We used the same comprehension test presented in experiment 1

3.1.5. Apparatus. The eye fixations of the subjects were monitored and recorded with the same eye tracking system used in experiment 1.

3.1.6. Procedure. The overall procedure involved the same three stages used in experiment 1. In the first stage, we constituted 40 high and 40 low spatial and mechanical groups. Secondly, subjects were presented one of the four versions. Moreover, we registered eye movements. Finally we tested the comprehension with questionnaire.
3.2. Results.

3.2.1. Comprehension performance. High spatial learners performed better than low spatial learners, \( F(1, 72) = 7, p = .01 \). Learners with an animated illustration performed better than learners with a static illustration, \( F(1, 72) = 6.86, p = .01 \). Nevertheless, we did not find a positive effect of the signaling cueing.

The effect of the comprehension indicators was significant: configuration scores were higher than kinematics scores which were higher than the functional model scores, \( F (2, 144) = 394.72, p < .0001 \).

3.2.2. Eye tracking measures. We analyzed the eye fixations of 75 subjects. So, we created five specific AOI, marked in figure 2.

3.2.3. Number of fixations. Results indicated a higher number of fixations when the diagrams was animated than when the diagram was static, \( F(1, 66) = 15.28, p < .001 \). The number of fixations in the AOI 3 was higher than the number of fixations in the AOI 4 which was higher than the number of fixations in the AOI 1 & 2, which was also higher than the number of fixations in the AOI 5, \( F (6, 396) = 196.75, p < .0001 \). The number of fixations in the AOI 1, 2 & 3 was higher for the animated diagrams than for the static diagram, \( F(6, 396) = 9.95, p < .0001 \).

3.3.3. Transitions between the AOI. The number of transitions was higher for the animated diagram than for the static diagram, \( F(1, 66) = 20.58, p < .0001 \). The number of local transitions was higher than the number of global transitions and this last one was higher than the causal chain transitions, \( F(2, 132) = 7.13, p = .001 \). Moreover, results showed a significant interaction effect between the different types of transitions and the presentation format, \( F(2, 132) = 7.13, p = .001 \). The effect of the transition type is more important for the animated diagram.

4. General Discussion

Comprehension test performances in experiment 1 showed a benefit of the controllable modalities, particularly when the task is oriented toward a mental model level. The full control animation seems to be the most efficient type of control for an effective integration of the mental model of a complex mechanical system. The orientation of attention by a specific task level showed that the building of the functional mental model was enhanced when the focus of this attention was directed on the functional model and on the kinematics of the system. Nevertheless, we failed to show a positive effect of signaling cues on comprehension. Only the explicit verbal orientation of attention has influenced the active building of an accurate functional mental model. This attentional feature of learning allows an efficient integration activity of the different elements of the device and of the relations between these elements according to the causal chain of the system.

The eye tracking measures showed that the number of fixations was more important in the AOI showing the relevant kinematics of the system. The results obtained from the study of the transitions between the different AOI suggest that the learners use the animated features and the controllability of the motions to process the relevant information, which in turn allows them to construct a model of the causal chain. Explicit verbal orientation of attention allowed the learners to efficiently regulate their strategy to select and to process the relevant information of the diagram. The implicit non-verbal signaling technique does not lead to the same results.

5. References