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Research report

Reducing the transience effect of animations does not (always) lead to better performance in children learning a complex hand procedure

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ABSTRACT

When large amounts of information are presented in long-section animations, or videos, depicting hand procedures, a transient information effect has often been shown to potentially weaken the superiority of dynamic visualizations over static graphics and to increase cognitive load. In the present paper, 103 ten-year-old children learnt to tie complex nautical knots from either a video of hand movements or from a static graphics presentation. Experiment 1 extended previous studies in the field using a conventional sequential presentation of the knots, under four conditions (long-section animation, short-section animation, long-section static graphics and short-section static graphics), but in a more "ecological" learning task than the majority of previous studies, involving a combination of observation and practice. In Experiment 2, with the same task and the same conditions, transience was reduced using animated simultaneous presentations. Results showed that long-section animation did not always lose its superiority over static graphics in this type of learning task. In addition to the transient information effect of the cognitive load theory, complementary explanations in terms of inhibition processes, attentional continuity and task affordance are suggested.

1. Introduction

Computer animations have been shown to be superior to their static counterparts for learning skills involving dynamic processes (Bernay & Bétrancourt, 2016; Betrancourt, 2005; Boucheix & Schneider, 2009; Tversky, Morrison, & Betrancourt, 2002; Höffler & Leutner, 2007; Lowe & Schnotz, 2008). However, this effect is limited to restricted learning conditions and tasks and is not systematic. A major issue concerns the intrinsic transience of dynamic visualization (Leahy & Sweller, 2011; Lowe, 1999, 2003, 2004; Spanjers, Van Gog, & Van Merrienboer, 2010; Sweller, Ayres, & Kalyuga, 2011; Wouters, Paas & van Merriënboer, 2008). In this paper, we are interested in the transient information effect in learning from computer animations like videos. Bétrancourt and Tversky (2000) defined the notion of computer animation with its transience aspect as follows: "computer animation refers to any application which generates a series of frames, so that each frame appears as an alteration of the previous one, and where the sequence of frames is determined either by the designer or the user" (p. 313). Thus, when presented with transient information, learners must simultaneously store, process and link both previous and current information. As a consequence, learning and/or comprehending from transient information such as videos or animations could be very resource demanding, and potentially result in severe impairment of the quality of the mental model built from the animation (Lowe & Boucheix, 2008, 2011). Based on empirical research, the Cognitive Load Theory postulates that working memory is limited in both capacity and duration (Sweller et al., 2011); taking this line, information transience can be considered to have negative load consequences on learners' working memory (Leahy & Sweller, 2011; Lowe, 1999; Wong, Leahy, Marcus, & Sweller, 2012).

Despite this negative aspect of animation transience, previous research has demonstrated that animated presentations are particularly beneficial and superior to their static counterparts when learning materials are based on human movements, due to the human ability to learn movement tasks by observation (Ayres, Marcus, Chan, & Qian, 2009; Höffler & Leutner, 2007; Marcus, Cleary, Wong, & Ayres, 2013; van Gog, Paas, Marcus, Ayres, & Sweller, 2009; Wong, Marcus, Ayres, Smith, Cooper, Paas & Sweller, 2009; Wong et al., 2012; and recently, Brucker, Ehlis,

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Häußinger, Fallgatter & Gerjets, 2015 who provided brain imagery information). One explanation of this ability to learn movements by direct observation is the existence of a highly effective mirror neuron system (Rizzolatti & Craighero, 2004; see also van Gog et al., 2009).

However, other recent research (Wong et al., 2012, see also; Ganier & de Vries, 2016) showed that for complex procedures involving a large amount of transience and a large number of steps, which could exceed the limits of working memory capacity, the superiority of animation over its static counterparts could decrease (with a significant fall in the positive effect of a dynamic presentation). Indeed, as suggested in the Animation Processing Model (Hasler, Kersten & Sweller, 2007; Lowe & Boucheix, 2008; Boucheix, Lowe, Putri, & Groff, 2013; Lowe & Boucheix, 2016), learning long series of movements (here of human movements) might require not only observing and imitating gestures, but also storing well-structured series of events in long-term memory, as well as understanding how they are linked.

Therefore, the findings from empirical research comparing dynamic visualizations and static graphics in learning hand procedures, with the transient information effect in learning from these animations or videos, do not always seem to be consistent. We suggest that at least three issues arise from previous research.

(i) A long series of permanent static graphics showing the key steps of a process, involving demanding inferences in order to link the steps presented in still images, could drain the limited cognitive resources of a learner's working memory as much as, or even more than, a transient animation. There could be *a static presentation effect* on cognitive load, which could be greater than -or as great as-the transient information effect for videos showing hand procedures.

(ii) This potential negative effect of static presentations compared to animations could increase in a task involving a more *ecological learning situation* (e.g. a combination of watching the video and practicing the procedure) than in the conventional learning-and-recall procedure used by the great majority of the previous studies on learning hand procedures from dynamic visualizations. There may be an "*Animation-task affordance*" effect (Lowe, Schnotz, & Rasch, 2010).

(iii) Furthermore, many previous experiments involving long transient information processing used a segmentation technique (Spanjers et al., 2010; Wong et al., 2012). This technique consists in dividing the dynamic presentation into smaller pieces of information to provide the learners with small, but supposedly meaningful parts of the animation, in order to reduce the amount of transience and its effects on working memory demands. However, the conventional *segmentation technique* used to reduce transience, usually addressed the issue of transience within but not between segments, and a significant part of the transience still remained. Additionally, the segments provided (nature and size) may not have matched the learners' information needs.

The aim of this paper was to address these three issues in two experiments. The paper is organized as follows. First, the three issues highlighted above will be developed within the literature review section. Secondly, the hypotheses will be presented. Thirdly, in order to investigate whether reducing the transient effect of animation, compared to the permanence of static graphics, would improve the performance of ten-year-old children learning a complex hand procedure (tying nautical knots) from dynamic visualizations, we carried out two experiments, with different groups of 10-year-old children. Fourthly, we compare the results of the two experiments. Finally, in the discussion section, we examine how our findings differ from or support those of previous studies and their contributions to the field.

2. The transience effect of animations: empirical and theoretical background

In their study, Wong et al. (2012, study 1) followed the line of previous research on the negative effect of transient information on learning from dynamic and multimedia presentations (Hasler et al., 2007; Leahy & Sweller, 2011; Mayer, Hegarty, Mayer, & Campbell, 2005; Sweller et al., 2011). They tested the hypothesis that when large amounts of information are presented in long-section animations, the transient information should weaken the superiority of dynamic visualizations over static graphics in learning a hand-movement task, by comparing the effects on comprehension of long vs. short sections of animation and long vs. short sections of static graphics; 10- and 11-year-old children were shown an origami task, with a realistic video showing hands performing the sequence of movement.

It was predicted that under the short-section conditions, using the same type of segmentation technique as in previous research (Mayer & Chandler, 2001; Moreno, 2007; Spanjers et al., 2010; Spanjers, Wouters, van Gog & van Merriënboer, 2011), the amount of transient information provided by the animation would not exceed working memory limits, and that the animation showing realistic movements would be superior to static graphics. By contrast, under the long-section presentation conditions, cognitive resource demands would exceed working memory capacity. Under this condition, animation would lose its advantage over a long series of static graphics. Thus, the authors expected to observe an interaction between section length (short vs. long) and presentation format (animated vs. static) in performance of the origami task. This hypothesis was confirmed; the interaction was significant (but ordinal only), showing that animation was better than static graphics under the short-section conditions. For the long-section conditions, learning performance was similar under the animated and static graphics conditions. While the main effect of format was significant (animation was superior to static graphics), the main effect of section size was not significant and remained unclear, especially for the animated presentation. These important and very interesting results did not resolve the question of the transience effect on cognitive load, with regard to the three main issues highlighted above and developed below, namely, the possible static presentation effect, the "Animation-task affordance" effect, and the segmentation of transient information.

2.1. A "static presentation effect" on cognitive load?

As mentioned above, we postulate that there could be *a static presentation effect* on cognitive load, potentially greater than (or at least as great as) the transient information effect for videos showing hand procedures. From previous empirical results, it has often been stated that the processing difficulties related to the transience of animation do not occur with static graphics, where the information remains available to the learners (Ayres et al., 2009; Höffler & Leutner, 2007; Marcus et al., 2013; Mayer et al., 2005; van Gog et al., 2009; Wong, Marcus, Ayres, Smith, Cooper, Paas & Sweller, 2009, and more recently see; Ganier & de Vries, 2016). Therefore, static graphics lead to better comprehension than animations (see Betrancourt, 2005; Boucheix & Schneider, 2009; Hegarty, Kriz, & Cate, 2003; Mayer, DeLeeuw, & Ayres, 2007; Mayer et al., 2005). Although animations are transient in nature, they provide learners with concrete information about temporal changes, whereas static pictures require the learner to infer temporal changes between the frames. The ability to infer the dynamics from a static presentation of key steps has been shown to be highly related to: (i) prior knowledge of the subject matter, particularly for young learners, and (ii) the temporal distance between the key steps presented in the pictures (Arguel & Jamet, 2009; Lowe & Schnotz, 2008; Lowe, 1999, 2003).

Another potential difficulty arises with static pictures used to depict hand procedures with a strong inherent temporal constraint. When the task involves a large amount of information, static graphics could demand extensive visual searching between pictures, inhibition of non-relevant information, and hence competition for attention (see Barrouillet, Bernardin, Portrat, Vergauwe, & Camos, 2007; Baddeley, 1992; Leahy & Sweller, 2011; Wong et al., 2012; and also Lowe & Boucheix, 2008; Lowe & Boucheix, 2011; Boucheix et al., 2013; Lowe & Boucheix, 2016; Schnotz & Lowe, 2008). This potential source of extraneous cognitive load (Leahy & Sweller, 2011) seems to be different from the cognitive load related to transience in hand procedures. It requires the inhibition of irrelevant information, particularly when there are a large number of pictures. For example, Arguel and Jamet (2009) found that learning a first aid procedure was improved by combining video and static pictures. However, they also found that the number of images made a significant difference; a small number of pictures (4 per step of the procedure: low frequency) was more effective than a large number (9 per step: high frequency). The extra processing demands required by a series of static pictures could raise the extraneous cognitive load (Paas & Sweller, 2014).

Furthermore, presenting a series of static pictures might also break the visual continuity of the hand procedure. To date, this aspect of learning hand movements has received little attention in the literature. For hand-movement tasks, videos provide the relevant information continuously, at the right time and in the right place. Via the model's hands, videos direct and guide the learner's attention toward the most relevant events. The continuous hand movements may keep attentional continuity and could help learners to build and link events to form more super-ordinate structures and improve their comprehension and memory, in other words, turning patterns of hand movements into meaningful events (Huff, Schwan, & Garsoffky, 2011). What we will call here "*the attentional continuity effect*" of continuous animation could explain part of the advantage of animated presentation. This assumption has been proposed and tested empirically within the framework of the recently developed "Attentional Theory of Cinematic Continuity" (AToCC) (Smith, 2012; Smith, Levin, & Cutting, 2012) in relation to film editing techniques such as camera angle effects (see Berliner & Cohen, 2011; Germeys & d'Ydewalle, 2007; Smith, 2006).

2.2. The "Animation-task affordance" effect

In a previous study, Lowe et al. (2010) introduced the idea of aligning affordances of graphics with learning task requirements. In almost all experimental studies on hand procedures (e.g. origami, tying knots, first aid procedures), the same learning-and-recall experimental design has been used. The procedure usually comprises two stages. The first is a learning phase, in which the learner observes on-screen pictorial material (animated or static), without access to real objects (paper, string etc.). The goal is to understand the steps of the procedure and store them in short- and long-term memory, within a strict time limit. The second stage involves recall, without access to the video. This stage could include a demonstration with real objects. This procedure is fully justified for methodological reasons (particularly the limited study time, and when the specific goal is to investigate the capacity of working memory resources). However, this is not how procedures are typically learnt from videos in everyday or ecological situations, in which the learner alternates between watching the video and practicing the hand procedure. This combination of observation and practice was used by Schwan and Riempp (2004) in a knot-tying task. However, they used only an animated format of interactive and non-interactive videos, leaving unanswered the question of whether the superiority of animation over static graphics would remain when the task combined observation and practice. In that situation, animation and static graphics remain equally available, as they can both be repeated at will during the learning session, and the effect of transience could thus differ from a traditional learning-and-recall task.

2.3. The segmentation of transient information

In most studies using segmentation techniques in dynamic presentations (for a review, see Spanjers et al., 2010; see also Wong et al., 2012; see also the meta-analyses on animations by Höffler & Leutner, 2007 and Bernay & Bétrancourt, 2016), segments are presented sequentially throughout the natural time-course of the process. Thus, although the whole process is divided into short sections, the reduction of transience remains limited to within each segment. This means that transience still remains between segments throughout the process. Currently, it is not known whether it is easier or more difficult to infer transient information occurring between than within segments (Lowe & Schnotz, 2008). Another technique that could reduce both the within- and between-segment transience of animations (Groff et al., 2014; Morand & Bétrancourt, 2010; Ploetzner & Lowe, 2014) involves presenting short sections of a whole animation (small animations) showing the different stages of the dynamic process simultaneously (see Fig. 3 below). They are shown on the screen simultaneously, side by side, in a continuous loop, like short-section animations. For example, when a learner watches the section showing the final stage of the dynamic process, the section showing the first phase can still be seen on the screen and is thus continuously available.

Previous research has used both simultaneous and sequential presentations of static graphics showing a temporal process (Boucheix & Schneider, 2009; Imhof, Scheiter, & Gerjets, 2011, 2012; Kim, Yoon, Whang, Tversky, & Morrison, 2007; Lowe & Schnotz, 2008), whereas animations are usually only presented sequentially (Tversky et al., 2002; Betrancourt, 2005; Höffler & Leutner, 2007; Lowe & Schnotz, 2008). In this conventional sequential presentation, each new frame is an alteration of the previous one, so that in most studies, the sequentiality of the process is inevitably confounded with animation of the display's components. The few studies in which animation and sequentiality have been disentangled show that this distinction could be important, although the results seem inconsistent (Groff et al., 2014; Morand & Bétrancourt, 2010; Ploetzner & Lowe, 2014).

Some studies found that learners' performance was better under the simultaneous than under the sequential condition (see the study by Morand & Bétrancourt, 2010, about the meiosis process in biology, or more recently the study by Ploetzner & Lowe, 2014, on navigational courses that a yacht can sail relative to wind direction). From these studies, it appears that simultaneous presentation of the dynamic steps of the process encourages active comparison of steps and relational processing. Such strategies may lead to the extraction of higher order relationships, resulting in the elaboration of more abstract spatio-temporal representations.

However, other studies found that the superiority of simultaneous over sequential presentation in animations did not always occur, and may even have drawbacks. For example, Groff et al. (2014) compared visual alternatives to spoken messages about disrupted services in French train stations. Loudspeaker messages (e.g. "*Your attention please, contrary to the previous information, TGV number 3458 for Paris will not leave from platform B but from platform D. Please take the underground passage*") are not accessible to travelers with hearing problems. The results of this study revealed that the sequential animated display was the most effective way of presenting the information, and the simultaneous animated condition the least effective. Eye-tracking data showed that in the case of animations presented simultaneously, the small side-by-side animations seemed to compete for the viewer's attention, resulting in additional, and costly, visual searching time. Moreover, explicit inhibition of salient but irrelevant information during the time-locked comprehension process could be required. In sum, using simultaneous, continuous presentations of small sections of the animation, showing the different phases of the process, could reduce the between-segment transience effect due to the loss of elements of information presented in long sections. Simultaneous presentations could allow comparison of the short sections of the animations, which may help build conceptual relations. However, they may also make it more difficult to take in the steps of the process progressively, particularly when the process has a very constrained temporal structure.

3. The present study

In our experiment, we chose a hand-procedure task, tying knots, already used in previous studies (see for example, Garland & Sanchez, 2013; Marcus et al., 2013; Schwan & Riempp, 2004). We used a more ecological protocol than the conventional learning and recall, combining watching the video and practicing the knot (as in Schwan & Riempp, 2004). The procedure of tying a complex knot involves large amounts of transience for young children (Budworth, 2004; Collectif Coop Breizh, 2011; see also, Marcus et al., 2013; Garland & Sanchez, 2013; Schwan & Riempp, 2004). Following the approach of Wong et al. (2012), we compared transient (videos) vs. permanent (static graphics) presentations using long and short sections of information.

According to the cognitive load theory, working memory is limited in both capacity and duration when learning new and complex contents from both static and dynamic visualizations. However, there is a human ability to learn movement tasks by observation, thanks to the existence of an effective mirror neuron system (Rizzolatti & Craighero, 2004). Furthermore, "*the attentional continuity effect*", developed from the "Attentional Theory of Cinematic Continuity" (AToCC, Smith, 2012), could foster learning from dynamic presentations of procedures. From these theoretical frameworks we predicted *(hypothesis 1a)* that animation would yield better performance than static graphics. This prediction is consistent with the results of previous empirical research on hand procedure learning (e.g. Ayres et al., 2009; Höffler & Leutner, 2007; Marcus et al., 2013; Wong et al., 2012; Wong, Marcus, Ayres, Smith, Cooper, Paas & Sweller, 2009; van Gog et al., 2009). Indeed, realistic dynamic visualizations provide directly relevant movements at the right time and in the right place. By contrast, with static graphics, learners have to mentally construct the dynamics. This involves: (i) finding relevant information in the right place, (ii) inhibiting irrelevant information, and (iii) inferring the movement by processing the series of pictures. These processes might impose a strong demand on limited perceptual and cognitive resources in working memory and as a result impair performance.

We did not predict that a long-section animation would lose its advantage over long-section static graphics. Firstly, for processes with a linear and serial temporal course, both short- and long-section animations deliver relevant information about the hand movements (e.g. making a loop) at the right time and in the right place. Moreover, in animated presentations of hand-movement procedures, the perceptual salience of hand-object motion and its relevance for the task goal are usually well aligned (Lowe, 2003). However, presenting this information through a series of static graphics (in short and long sections) requires the construction of an internal mental model, leading not only to additional visual searching time amongst pictures (to make inferences about minimal movements), but also to the need to actively inhibit irrelevant information within and across pictures. Inhibition requires great cognitive control involving executive functions and focused attention, particularly in children, and may result in increased cognitive load, especially under the long-section condition, with potential negative consequences on learning performance.

Secondly, when the difference in transience between short- and long-section animations is limited to information within the section and does not apply between sections, transience would remain relatively high under both short and long conditions (Wong et al., 2012).

Thirdly, in our study, participants learned to tie knots by watching a video and practicing until they were able to tie the knot without the video. During the learning phase, they could alternate between watching the video and practicing the knots at will (but without any user-control features, as in Schwan & Riempp, 2004) and could restart the animation when it reached the end (see the method section). In this way, learners could watch the steps several times, and the effect of transience might consequently decrease, even with long sections. Thus, we expected *(hypothesis 1b)* that the superiority of animation over static graphics would remain in the long-section condition when using a combination of observation and practice.

In the first experiment, the animation was presented in a linear and sequential manner. In the second experiment, several (four) videos were presented simultaneously on the screen, in short and long sections (see method section below). These simultaneous presentation conditions were compared with a similar series of static graphic conditions in short and long sections. However, the static graphics were not presented sequentially, but in the form of a grid, allowing direct comparison of the pictures, under both short- and long-section conditions (see method section below).

In the simultaneous long-section condition, the continuous videos showing the knot-tying procedure in animated sections allowed the learner to make constant comparisons between each step. In this way, transience was limited to within sections, instead of occurring between sections. Between-section transience was thus reduced compared to the sequential presentation of long-section animations. The learners kept the benefit of an animated presentation, without the disadvantages of the transience of a long sequential presentation. Participants could continuously view and compare the different steps of the dynamic procedure. This condition might help the processing in working memory, and the storage in long-term memory of the steps of the hand procedure. However, because of their intrinsic multiple dynamics, simultaneous short-section animations are equally salient but not all relevant to the learners' needs at any given moment of the procedure. As a result, learners must inhibit irrelevant information that competes for their attention (as in a series of static pictures) and this added processing could increase perceptual and cognitive resource demands.

In the short-section animated presentation, the series of short animations were presented in turn, from the beginning to the end of the procedure. However, the presentation retained a simultaneous nature; as the first video section ended, the second section started, and so forth. But at the end of each short-section video, the last frame remained on screen, showing the state of the knot. In this way, reference to temporal continuity was maintained, allowing comparison between steps. This form of presentation thus reduced the competition for attention between the series of short-section videos. As a result, the perceptual and cognitive resource demands on the learners should be lower than in the simultaneous long-section condition.

For Experiment two, using the same theoretical framework as experiment one, we predicted first *(hypothesis 2a)* that animation would be superior to static graphics, because realistic dynamic visualizations convey a more accurate indication of relevant movements and how they are linked. Regarding long and short sections of the animations, on the one hand, the long-section presentation with simultaneous, continuous short videos should allow learners to view and process all the dynamic sections continuously, whereas in the short-section presentation, learners had to store the previous short section before processing the next one. On the other hand, with long sections, the possible competition for attention between the simultaneous videos could involve additional inhibition processes, which could impair comprehension and increase cognitive load and hence learning time. With short sections, there was no such competition for attention, because each short-section animation of the procedure was played alternately and sequentially. Not only would the amount of transient information of one short-section video not exceed the limits of working memory, but also the freezing of the final frame of the previous section could help the learners to mentally link sections. Thus, it was predicted (*hypothesis 2b*) that participants in the sequential presentation condition would outperform participants in the simultaneous presentation condition, especially with long sections. Finally, to examine in more detail this hypothesis, and because Experiments 1 and 2 used the same material and the same experimental design, we were able to compare their results statistically, focusing on sequential vs. simultaneous presentations.

4. Experiment 1

The aim of Experiment 1 was to test the transient information effect, like Wong et al. (2012), using a similar but different task, tying knots, and a different procedure, learning by observation and practice. An experimental plan was designed with presentation format (animated vs. static) and section length (long vs. short) as between-subjects factors. We used several knots with different levels of complexity, and type of knot (simple vs. complex) was the within-subjects factor.

4.1. Method

4.1.1. Participants

Participants were 49 children (25 female, 24 male) from French primary schools (with varied socio-cultural backgrounds), with a mean age of 10.36 years ($SD = 0.52$). Parental and teacher consent for participation was obtained. Participants were allocated to one of four experimental groups: short-section animation ($n = 13$); short-section static graphics ($n = 12$); long-section animation ($n = 13$); long-section static graphics ($n = 11$). Eight left-handed participants were allocated to different groups. We checked (questionnaire) that none of the children had prior knowledge of nautical knots or sailing experience. All but three participants were able to tie their shoelaces.

4.1.2. Material

The task involved tying nautical knots. Three knots with different levels of complexity were used. The first, *a figure-eight knot*, was used for familiarization in a pre-training phase. For the main learning task, there were two knots with different levels of complexity: the relatively simple *clove hitch*, and the more complex *bowline* (on this point, see Budworth, 2004; Collectif Coop Breizh, 2011; and also Schwan & Riempp, 2004; Marcus et al., 2013). The procedures for the three knots were filmed using a Sony-DCR-TRV950E digital camera. The learning material showed hands tying the knots (Fig. 1).

We followed the recommendations of previous studies on tying knots: (i) hand actions were shown (a study by Marcus et al., 2013 demonstrated that animations showing hand actions are more effective than those that do not); (ii) we used an over-the-shoulder view matching the learner's own perspective, which has been shown to be more effective than a face-to-face view (Garland & Sanchez, 2013).

In the origami task used in Wong et al. (2012) the procedure involved a series of folds. Thus, it was easy to produce small segments, relatively similar in size, one for each fold, each fold then divided into a series of detailed single gestures (see Wong et al., 2012, Fig. 1, p. 451, and also Kurby & Zacks, 2007, for segmentation principles). By contrast, tying knots is a more continuous procedure, making it more difficult to segment on the basis of discreet gestures. To determine the number of steps and screenshots within each step, a fine balance was required between using a very large number of frames showing small but potentially meaningless gestures and choosing a smaller number of frames with more meaningful pieces of information. This was a particularly important issue when designing the long-section static presentation. The same content was given to all groups (the video frames and static graphics were the same size, displayed on a 24-inch LCD monitor).

A pilot test using the segmentation principles of two previous studies, one using an origami task (Wong et al., 2012, p. 451) and the other knot tying (Marcus et al., 2013, p. 2174) showed that in order to provide a good level of clarity, and to avoid any difficulty of processing inferences between frames, 15 steps were needed for the figure-eight knot (familiarization phase), 16 steps for the clove hitch, and 18 for the bowline.[1] The size of the steps was based on the type of single movement used in the study by Wong et al. (2012, see p. 451, Fig. 1). The goal was to optimize three related constraints: (i) to ensure clarity of movement continuity, (ii) to maintain a sufficiently large amount of information (15–18 steps appears to be beyond the working memory capacity of 10-year-old children), (iii) to minimize the number of frames (on this point, see also Arguel & Jamet, 2009; Ayres et al., 2009; Wong et al., 2012). There were only images, with no text and no sound. The presentation rate of the videos was 25 frames per second.

The long-section animation consisted of a single video presenting the whole procedure for each knot in conventional (i.e. sequential) manner. Running time was 23 s for the 15 steps of the figure-eight knot (pre-training), 32 s for the 16 steps of the clove hitch (i.e. an average of 2 s per step), and 29 s for the 18 steps of the bowline (an average of 1.6 s per step). At the beginning of the presentation, a slide informed the participants that they would be shown two successive presentations of the section with the same duration (see also Wong et al., 2012, p. 452). The whole presentation (two successive presentations of the knot) thus took 48 s for the pre-training figure-eight knot, 66 s for the clove hitch, and 60 s for the bowline. These durations were shorter than the 250 s in the study by Wong et al. (2012). However, in the present study, at the end of each long section (a knot shown twice in succession), the animation could be watched again, at will, until the end of the learning phase (when the participant could tie the knot three times

[1] In their study, Marcus et al., 2013, used 24 steps (frames) for their bowline knot, but it seems from the picture in Fig. 2 on page 2174 that the bowline knot they used had an additional step -a loop on the end of the rope-compared to the more basic bowline knot we used in our study.

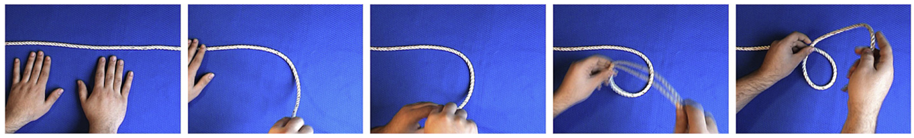

Fig. 1. An example of the segmentation used in the static graphics learning material, here at the beginning of the bowline knot.

without the video, see procedure below). The procedure was similar for the figure-eight knot in the pre-training phase.

The short-section animation was the long-section animation split into groups of steps. The bowline was split into 4 groups, each containing 3 to 6 steps. The clove hitch was split into 4 groups, each containing 3 or 4 steps. As in the procedure by Wong et al. (2012), participants were told that they would have to watch the same group of steps twice. Like the long-section animation, short sections were presented sequentially, as usual in animation presentations. The whole presentation time of the short-section animation was the same as for the long-section condition (66 s, 60 s and 48 s for the clove hitch, bowline and figure-eight knot respectively). Likewise, at the end of each short-section animation, it could be viewed again, at will, until the end of the learning phase (see procedure below).

The static graphics were screenshots of individual frames taken from the video. We used the same general principle as Wong et al. (2012) to select screenshots, namely how clearly they demonstrated the steps of the knot-tying procedure. The goal was also to control for information comparability between the animation and the static graphic conditions. For both the short- and long-section static graphics, running time was the same as the equivalent animation presentations (66 s for the clove hitch, 60 s for the bowline, and 48 s for the figure-eight), and they could be repeated at will during the learning phase. For both the videos and the static graphic slides, learners could not return to a previous segment. However, for the long-section static graphics, a single (sequential) scrollable file was used with minimal control (see Wong et al., 2012). In the short-section presentation, each section was presented twice. The videos and images were imported into the graphic design using Adobe First Software, and then integrated into the experimental design of the presentation conditions.

4.1.3. Task and procedure

The experiment took place in a quiet room of the participants' school. Each child sat at a table with a 24-inch (16/9) computer screen and the material needed for tying the knots: a piece of string for the bowline (and the figure-eight knot), a stick and a piece of string for the clove hitch (the same color as in the video). Participants were told that they had to learn to tie the knots from the videos (or static graphics) by observation and practice. During the learning phase, the learner could alternate between watching the video (or static graphics) and practicing the knot at will, but was not allowed to watch and practice simultaneously (following the same procedure as Schwan & Riempp, 2004). For each knot, they had to watch the demonstration and practice until they were able to tie the knots three times in the test phase, without the video (or static graphics presentation). Each child was videotaped (using a Canon Legria, HD, HF, S11) throughout the learning and test phases, framed to show the child's head and hands, the table and the computer screen.

The experimental procedure had three stages, one per knot (figure-eight, clove hitch and bowline), each comprising a learning phase followed by a test phase, and all presented under the same conditions. The order of presentation of the clove hitch and the bowline was counterbalanced across participants.

4.1.4. Data analysis

Based on the videos and log files (recorded automatically via log-file protocols), the behavior of each learner was recorded and analyzed. The main learning outcome measure was the time (in minutes and seconds) taken to tie the two knots three times without referring to the teaching material (video or static graphics). For each knot, the *total learning time* was broken down into: (i) *viewing time*, *i.e.* the overall time spent watching the presentation; (ii) *practicing time*, i.e. the overall time spent practicing (before the test stage), as in Schwan & Riempp, 2004. To ensure comparability between the two knots, each time measure was divided by the duration of the video (or static graphics presentation). The number of times the presentation was repeated was also recorded.

4.2. Results of experiment 1

Total learning time, viewing time and practicing time are presented in Table 1 for each knot and each experimental group. Table 1 is completed with Fig. 2, which provides graphical interactions, more directly available visually.

We conducted three *2* (format: animation vs. static graphics) $\times$ 2 (section length: short vs. long) $\times$ *2* (knot complexity: clove hitch vs. bowline) MANOVAs on the data, one for each learning outcome (overall learning time, viewing time and practicing time).

For the overall learning time, the MANOVA showed that learners needed less time to learn to tie the knots in the animated than in the static graphics format, $F(1,45) = 24.56$, $p < 0.0001$, $\eta^2 = 0.35$. It was shorter under the short-section than the long-section condition, $F(1, 45) = 5.92$, $p = 0.019$, $\eta^2 = 0.12$. An interaction was found between format and section length, $F(1, 45) = 4.52$, $p = 0.04$, $\eta 2 = 0.09$, indicating that the difference in learning time between animated and static graphic formats was greater under the long-section than the short-section condition. Univariate comparisons confirmed that the difference was significant under the long-section condition, $F(1, 45) = 23.97$, $p < 0.0001$, $d = 1.78$, and marginally significant under the short-section condition, $F(1, 45) = 4.01$, $p = 0.051$, $d = 0.91$. Finally, it took longer to learn the bowline, the most complex knot, than the simpler clove hitch, $F(1, 45) = 22.24$, $p < 0.0001$, $\eta^2 = 0.33$.

Next, the overall learning time was broken down into the time watching the video and the time practicing the knot, yielding a slightly different pattern of results. The MANOVA showed that learners spent less time viewing the video in the animated than in the static graphics format, $F(1, 45) = 17.38$, $p < 0.001$, $\eta^2 = 0.28$. Viewing time was only marginally shorter under the short-section than the long-section condition, $F(1, 45) = 3.69$, $p = 0.061$, $\eta^2 = 0.07$. There was no significant interaction between format and section, $F(1, 45) = 2.94$, $p = 0.093$, $\eta^2 = 0.06$. Unvariate comparisons (see Howell, 1997) indicated that the difference in viewing time between the animated and static graphics formats was significant for the long-section condition, $F(1, 45) = 16.92$, $p < 0.001$, $d = 1.27$, but not the short-section condition, $F(1, 45) = 3.08$, $p = 0.09$, $d = 0.67$. Again, viewing time was longer for the complex bowline than for the clove hitch, $F(1, 45) = 15.37$, $p < 0.001$, $\eta^2 = 0.25$. There was also a marginal knot type*format*section length interaction, $F(1, 45) = 3.86$, $p = 0.055$, $\eta^2 = 0.08$, indicating that the effects of

Table 1
Means *(and standard deviations)* of total learning time, viewing time and practicing time for each knot, in the animated and static conditions, as a function of section length (short versus long).

		Animated presentation		Static presentation	
		Short sections	Long section	Short section	Long section
Clove hitch	Viewing time	2.17*(0.98)*	2.66*(1.31)*	3.64*(1.95)*	4.58 (3.13)
	Practicing time	1.00*(0.56)*	1.18*(0.64)*	2.06*(1.62)*	3.67 (2.31)
	Overall learning time	*3.17(1.21)*	*3.84(1.79)*	*5.71(3.37)*	*8.26(4.79)*
Bowline	Viewing time	3.46*(1.50)*	3.16*(1.83)*	4.32*(2.25)*	6.83 (2.23)
	Practicing time	1.99*(0.78)*	2.08*(1.54)*	2.90*(1.42)*	4.79 (2.04)
	Overall learning time	*5.45(2.18)*	*5.24(3.32)*	*7.23(3.40)*	*11.63(3.69)*
Total overall learning time		**8.62*(2.81)***	**9.09*(4.66)***	**12.94(6.06)**	**19.89*(7.18)***

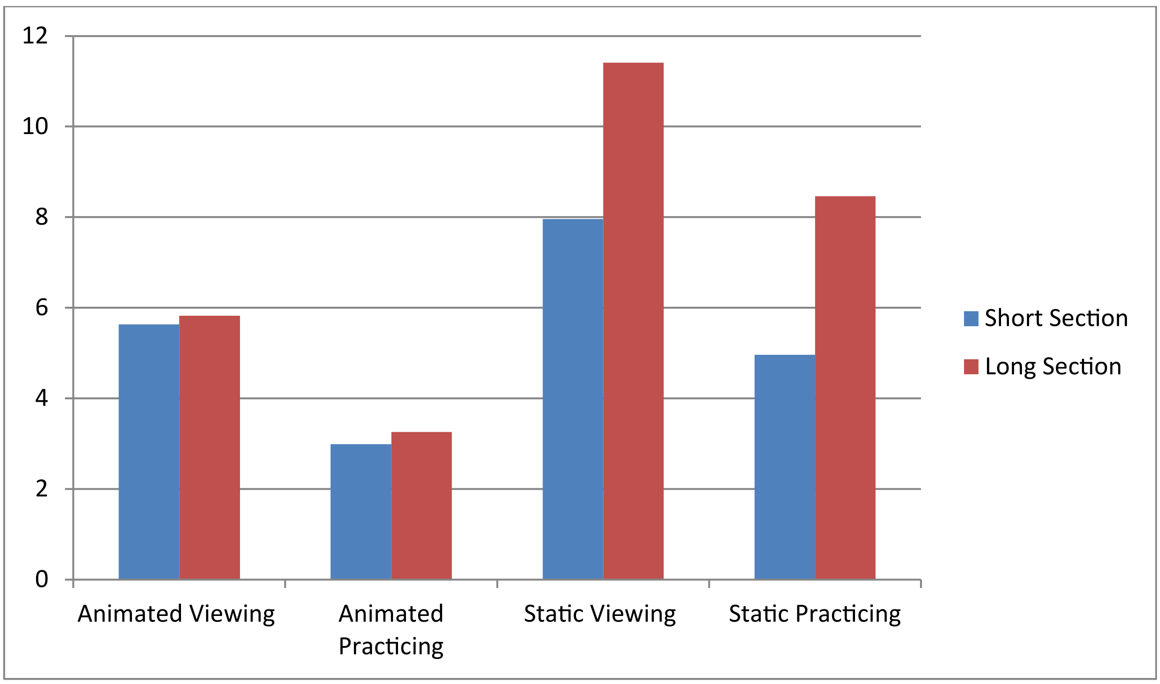

Fig. 2. Experiment 1, means of viewing and practicing times in animated and static presentation conditions for each section length.

format and section length were stronger for the bowline than for the clove hitch.

An interesting result was that the effect of the variables was more marked for practicing than for viewing time. The MANOVA revealed that learners needed less practicing time under the animated than under the static graphic condition, $F(1, 45) = 27.54$, $p < 0.0001$, $\eta^2 = 0.38$. They spent less time practicing under the short-section than the long-section condition, $F(1, 45) = 7.56$, $p < 0.01$, $\eta^2 = 0.14$. There was a format* section length interaction, $F(1, 45) = 5.53$, $p = 0.02$, $\eta^2 = 0.11$, showing that the difference in practicing time between animated and static graphics conditions was highly significant for the long-section condition, $F(1, 45) = 28.23$, $p < 0.0001$, $d = 1.51$, and less significant for the short-section condition, $F(1, 45) = 4.29$, $p < 0.05$, $d = 0.84$.

In sum, the results of Experiment 1 indicate that animation was more efficient than static graphics containing comparable information, even in a more ecological learning task. The effect of section length was significant, in favor of short sections. Moreover, when the amount of transient information was presented in long sections, the animation did not lose its superiority over static graphics. This result seems to differ from those of Wong et al. (2012); this will be discussed in the final discussion.

Sequential animations put a high cognitive load on working memory resources. However, in the case of manual tasks, they also deliver the relevant information continuously at the right time, and thus to some extent release learners from the demanding parallel activities involved in processing static graphics. Moreover, with static graphics, learners have to infer the relations between frames. Due to the large number of frames under static graphic conditions, many inferences are required, increasing the demands on working memory and hence learning time. In our static graphics conditions, the conceptual distance between two frames in terms of hand movements was small, facilitating the inferential process (Fig. 1). However, even under this condition, which provides learners with a high level of affordance for supporting inferences, processing the hand procedure involves generating a mental model, including the links between frames. This process takes time and is resource-demanding. Consequently, not only inferences but also other associated demanding activities are required during the learning process in which viewing and practicing alternate. These include visual searching between pictures, with comparison and competition for attention between frames, and inhibition of irrelevant information. These resource-demanding processes may have a stronger effect under the long-section than short-section static graphic condition. The effect of section length was only significant in the static graphics condition.

5. Experiment 2

In Experiment 1, the presentation of the information was sequential, such that the difference in transience between the short-section animation and static graphics conditions was limited to within each segment. Between-segment transience was similar in the static graphics and animation conditions, in which learners could not go back to previous segments. In Experiment 2, the transience of the animations was reduced by presenting short-section animations simultaneously, side-by-side. The procedure and tasks were the same as in Experiment 1, but with four different groups of children. The same experimental plan was also used, with *presentation format* (animated vs. static) and *section length* (long vs. short) as between-subjects factors. Finally, the same knots were used, with *type of knot* (simple vs. complex) as within-subjects factor.

5.1. Method

5.1.1. Participants

Participants were 54 children (27 female, 27 male) from French primary schools (from varied socio-cultural backgrounds), with a mean age of 10.33 years ($SD = 0.54$). Parental and teacher consent for participation was obtained. Participants were allocated to one of the four experimental groups: short-section animation ($n = 14$); short-section static graphics ($n = 13$); long-section animation ($n = 13$); long-section static graphics ($n = 14$). Seven left-handed children were allocated across the four groups. None of the children had prior knowledge of nautical knots or sailing experience. All but one of the participants could tie their shoelaces.

5.1.2. Material

The task and the material were exactly the same as in Experiment 1. The sections and the number of steps for each knot (the figure-eight knot for the familiarization phase, the clove hitch and the bowline for the main learning phase) were also exactly the same as in Experiment 1 (see section *3.1.2.* above). Presentation times in the four conditions were also exactly the same. The only difference between the two experimental conditions was that all the steps (and frames) were delivered sequentially in Experiment 1, and simultaneously in Experiment 2.

The long-section animation consisted of the simultaneous and continuous presentation of four short animations showing the steps of each section (see Fig. 3 for a screenshot of this presentation). The four animation sections were placed side by side on the screen (the same size as in Experiment 1), allowing the four sections to be constantly compared. As in Experiment 1, at the end of the presentation (two runs of the video, i.e. 48 s, 66 s and 60 s for the figure-eight, clove hitch and bowline respectively), the long-section animation could be repeated at will, with the same continuous, side-by-side display of the sections.

As in the long-section animation condition, the sections were presented side by side, but in the short-section animation condition, the first section was presented first. At the end of the animated section, the final frame of this section remained frozen on the screen. The second animated section then started, and at the end of this section, the final frame remained on the screen. This process was continued until the end of the four sections. The sections were always presented from left to right, i.e. from the beginning to the end of the procedure. Under this condition, comparison between sections (and steps) was only possible between the running animated sections and the final static frame of the previous section. This process continued until the end of the learning phase (48 s, 66 s and 60 s for the figure-eight, clove hitch and bowline respectively). The learner could repeat the presentation at will.

In the long-section static graphic condition, all the steps of the procedure (frames, taken from the original animation, as in Experiment 1) for the clove hitch and the bowline were presented simultaneously in a grid with 5 columns and 4 lines (5 columns $\times$ 3 lines for the figure-eight knot), which could be read in the conventional direction, left to right and top to bottom. This grid was presented for 66 s for the clove hitch and 60 s for the bowline (48 s for the figure-eight knot). The grid could be viewed again at the end of each presentation until the learner was able to tie the knot correctly three times without the graphics. The size of the pictures was the same under each condition and as in Experiment 1. During the pre-training trial with the figure-eight knot, we checked that all the children could read the pictures in the grid in order.

In the short-section static graphic condition, the steps of the first section were presented simultaneously twice, and remained on the screen. Then the steps of the second section were presented twice, and added to the frames of the first section, followed in similar fashion by the steps (frames) of the third and fourth sections. When the fourth section finished, all the frames formed a 5×4 grid (5×3 for the figure-eight knot), which disappeared at the end of the presentation time (i.e. 66 s for the clove hitch and 60 s for the bowline). The same presentation could be seen again at will. The sections were always presented from left to right and from top to bottom (i.e. from the beginning to the end of the procedure). Each section was presented for the same length of time. As in the long-section static graphics condition, frames could be compared.

5.1.3. Procedure, task and data analysis

The learning task combining viewing and practicing, and the data analyses were exactly the same as in Experiment 1.

5.2. Results

Total learning time, viewing time and practicing time are presented in Table 2 for each knot and each experimental group. Table 2 is completed with Fig. 4, which provides graphical interactions, more directly available visually.

Three *2* (format: animated vs. static graphics) x 2 (section length: short vs. long) x *2* (knot complexity: clove hitch vs. bowline) MANOVAs were conducted, one for each learning outcome (overall learning time, viewing time and practicing time).

For overall learning time, the MANOVA showed that learners needed less time to tie the knots in the animated than in the static format, $F(1, 50) = 5.23$, $p < 0.03$, $\eta^2 = 0.095$. Overall learning time was shorter under the short-section than the long-section

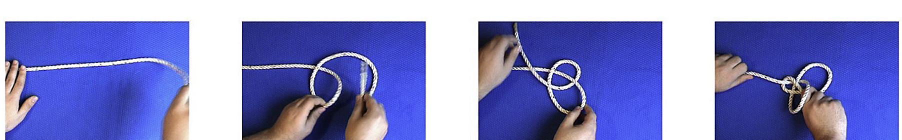

Fig. 3. A screenshot of the four animated sections shown simultaneously side by side. (Notice that the first picture on the left, showing the beginning of the first animated section corresponds to the frames presented in Fig. 1).

Table 2
Means *(and standard deviations)* of total learning time, viewing time and practicing time for each knot, under animated and static conditions, as a function of section length (short versus long).

		Animated presentation		Static presentation	
		Short sections	Long section	Short sections	Long section
Clove hitch	Viewing time	2.194 *(1.05)*	3.117 *(1.70)*	3.336 *(2.04)*	4.867 *(3.62)*
	Practicing time	1.279 *(0.79)*	1.951 *(1.39)*	1.981 *(1.52)*	3.338 *(3.31)*
	Overall learning time	3.47 *(1.76)*	5.07 *(2.82)*	5.32 *(3.42)*	8.2 *(6.85)*
Bowline	Viewing time	3.476 *(2.04)*	5.46 *(3.07)*	6.669 *(2.76)*	6.537 *(2.79)*
	Practicing time	2.340 *(1.22)*	4.155 *(2.57)*	2.499 *(1.32)*	4.070 *(2.79)*
	Overall learning time	5.81 *(3.15)*	9.62 *(5.47)*	9.17 *(3.91)*	10.61 *(5.26)*
Total overall learning time		**9.29 *(4.39)***	**14.68 *(6.92)***	**14.48 *(6.67)***	**18.81 *(10.51)***

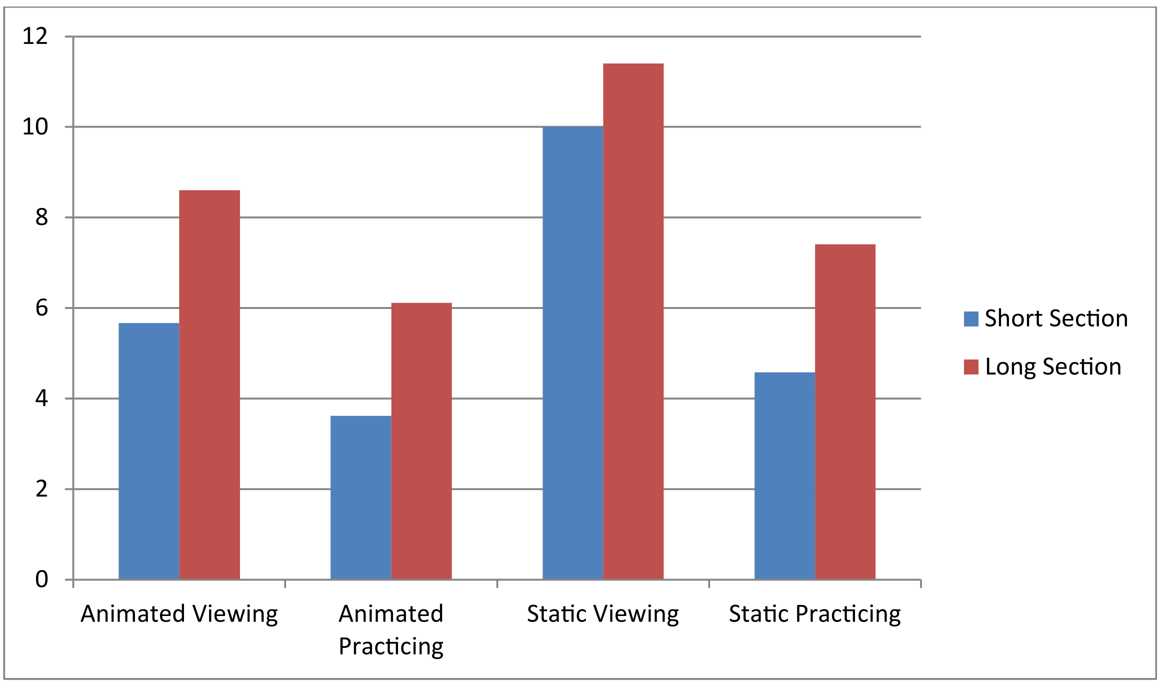

Fig. 4. Experiment 2, means of viewing and practicing times under animated and static presentation conditions for each section length.

condition, F (1, 50) = 5.70, p = 0.02, η^2 = 0.10. There was no interaction between format and section length, F (1, 50) = 0.07, p = 0.79. However, univariate comparisons (as proposed by Howell, 1997) indicated that the difference between the long-section animated and the long section static graphic conditions was not significant, F (1, 50) = 2.05, p = 0.16, d = 0.46, while there was a marginally significant difference between the short-section animated and short-section static graphic conditions, F (1, 50) = 3.25, p = 0.07, d = 0.92. In the animated format, participants learnt marginally faster with short than long sections, F (1, 50) = 3.51, p = 0.06, d = 0.93; however, with the static graphic format, the difference between the short and the long section conditions was not significant, F (1, 50) = 2.26, p = 0.14, d = 0.49. Finally, the bowline was again more difficult to learn than the clove hitch, F (1, 50) = 27.93, p < 0.0001, η^2 = 0.36. There was no other significant interaction.

Next, the overall learning time was broken down into viewing and practicing time.

For the viewing time, the MANOVA revealed that learners spent less time viewing the video in the animated than in the static graphics format, F (1, 50) = 9.81, p < 0.003, η^2 = 0.16. Viewing time was marginally shorter under the short-section condition than under the long-section condition, F (1, 50) = 3.55, p = 0.06, η^2 = 0.07. There was no format *section length interaction, F (1,50) = 0.05, p = 0.51. However, univariate comparisons indicated that the differences in viewing time between the animated and the static graphics formats were marginally significant under the long-section condition, F (1, 50) = 3.05, p = 0.086, d = 0.50, and were significant under the short-section condition, F (1, 50) = 7.19, p < 0.01, d = 1.07. Viewing time was also much longer for the bowline than for the clove hitch, F (50) = 33.11, p < 0.0001, η^2 = 0.40. Finally, there was a marginal second-order interaction between type of knot, format and section length, F (1, 50) = 3.31, p = 0.07, η^2 = 0.06. This interaction indicated that the effect of the two main factors, format and section length, were more pronounced for the bowline than for the clove hitch.

For practicing time, the MANOVA showed that learners spent the same time practicing under the animated and static graphic conditions, F (1, 50) = 1.23, p = 0.27, η^2 = 0.02. However, they practiced faster with short sections, F (1, 50) = 7.74, p = 0.007, η^2 = 0.13. The format*section length interaction was not significant, F (1, 50) = 0.05, ns. The bowline knot required longer practicing time than the clove hitch, F (1, 50) = 16.70, p < 0.001, η^2 = 0.25. There was a marginally significant interaction between type of knot and format, F (1, 50) = 3.32, p = 0.07, the difference between the two formats slightly varying according to the type of knot.

In sum, in Experiment 2, using a simultaneous presentation technique, participants needed less time to learn the knots with animation than with static graphics, and also with short sections. However, the two experiments produced a different pattern of results, suggesting differences in the cognitive processes involved in understanding manual skills from animation and static graphics. In Experiment 1, using a conventional sequential presentation, participants needed the same time to learn the knots in the short- and long-section animation conditions. Long-section animation maintained its superiority over long-section static graphics.

By contrast, in Experiment 2, with simultaneous presentation, learning times were longer in the long-than short-section animation, and long-section animation lost its advantage over long-section static graphics. One explanation for this difference is that under the long-section simultaneous animation condition, the four short section animations were shown continuously, allowing direct comparison between the sections of the procedure. This could also have a downside by causing competition for attention between the short-section animations, which had similar perceptual saliency. Moreover, motor skills such as knot tying have a very constrained temporal order. Thus, comparison processes between simultaneous sections may not be helpful, because what is important is to see the next step, without any other competing information. This may explain why the short-section animation condition produced the fastest learning time in Experiment 2 ($M = 9.29$, similar to the learning times of the short- and long-section animations in Experiment 1, $M = 8.62$ and $M = 9.09$, respectively). In the short-section animation condition of Experiment 2, the first animated section was presented first. The final frame of each section remained static on the screen, allowing the end result of previous sections to be compared with the currently running one. This provided optimal alignment between the perceptual salience of the information (dynamics) and its relevance to the temporal order constraints of the task. In the simultaneous long-section animation, perceptual salience was neither aligned with, nor well attuned to conceptual or procedural relevance.

In the following section, we investigate this issue further. Because the only difference in the design of the two experiments was the sequential vs. simultaneous presentation conditions, the data of the two experiments were analyzed together in order to investigate more precisely the role of sequential vs. simultaneous presentation of the animations.

6. Comparison of the two experiments: sequential and simultaneous presentations of animated and static graphics

To analyze the data of both Experiments 1 and 2, summarized in Fig. 5, we conducted three *2* (format: animation vs. static graphics) x 2 (section length: short vs. long) x 2 (temporal presentation: sequential −exp. 1- vs. simultaneous − exp. 2) × *2* (knot complexity: clove hitch vs. bowline) MANOVAs, one for each learning outcome (overall learning time, viewing time and practicing time).

For overall learning time, the MANOVA showed that participants needed less time to learn to tie the knots in the animated than in the static graphics format, $F(1, 95) = 22.30$, $p < 0.0001$, $\eta^2 = 0.19$, and with short than long sections, $F(1, 95) = 10.97$, $p = 0.001$, $\eta^2 = 0.10$. Learning times seemed shorter in the sequential than in the simultaneous presentation condition (M sequential $= 12.34$, $SD = 6.81$; M simultaneous $= 14.31$, $SD = 8.05$), but the difference was not significant, $F(1, 95) = 1.70$, $p = 0.20$, $\eta^2 = 0.02$. However, because the goal of the comparison was to analyze sequential vs. simultaneous presentation of the animations, we performed univariate comparisons, as suggested by Howell (1997). These analyses revealed no difference between sequential and simultaneous presentation for short-section animation ($F(1, 95) = 0.7$, *ns.*), short-section static graphics ($F(1,95) = 0.35$, *ns.*), or long-section static graphics ($F(1,95) = 0.18$, *ns*). However, the difference was significant for long-section animation, in favor of the sequential condition, $F(1, 95) = 4.74$, $p = 0.03$, $d = 0.32$. In both experiments, the bowline knot took longer to learn than the clove hitch, $F(1, 95) = 47.93$, $p < 0.0001$, $\eta^2 = 0.33$.

Overall learning time was then broken down into viewing time and practicing time. For viewing time, the MANOVA revealed that learners spent less time viewing the video in the animated than in the static graphics format, $F(1, 95) = 25.13$, $p < 0.0001$, $\eta^2 = 0.21$. Viewing time was also shorter with short than long sections, $F(1, 95) = 7.00$, $p < 0.01$, $\eta^2 = 0.07$, and apparently under the sequential than the simultaneous condition (M sequential $= 7.55$, $SD = 3.94$; M simultaneous $= 8.90$, $SD = 4.62$), but the difference failed to reach significance, $F(1, 95) = 2.57$, $p = 0.11$, $\eta^2 = 0.03$. However, univariate comparisons showed that there was no difference between sequential and simultaneous presentation for short-section animation ($F(1, 95) = 0.01$, *ns.*), short-section static graphics ($F(1, 95) = 1.80$, $p = 0.18$, $d = 0.51$), or long-section static graphics ($F(1,95) = 0.01$, *ns*). However, the difference was marginally significant for long-section animation, in favor of the sequential condition, $F(1,95) = 3.40$ $p = 0.06$, $d = 0.82$. Participants took longer to learn the bowline than the clove hitch, $F(1, 95) = 46.90$, $p < 0.0001$, $\eta^2 = 0.33$. The interaction between temporal presentation (sequential vs. simultaneous) and type of knot was significant, $F(1, 95) = 4.05$, $p < 0.05$, $\eta^2 = 0.04$; viewing times for the clove hitch were similar with sequential and simultaneous presentation, but were shorter under the sequential condition for the more complex bowline knot, $F(1, 95) = 5.44$, $p = 0.02$.

The MANOVA indicated that practicing time was shorter in the animated than in the static graphics format, $F(1, 95) = 14.87$, $p < 0.001$, $\eta^2 = 0.13$, and under the short-than long-section condition, $F(1, 95) = 14.32$, $p < 0.001$, $\eta^2 = 0.13$. There was no effect of temporal presentation, sequential vs. simultaneous, $F(1, 95) = 0.62$, $p = 0.043$, $\eta^2 = 0.006$. Moreover, univariate comparisons revealed that there was no difference between sequential and simultaneous presentations for short-section animation ($F(1, 95) = 0.28$, $p = 0.59$, $d = 0.41$), short-section static graphics ($F(1, 95) = 0.16$, *ns*), or long-section static graphics ($F(1, 95) = 0.74$, $p = 0.39$, $d = 0.24$). By contrast, the difference was significant for long-section animation, in favor of the sequential condition, $F(1, 95) = 5.57$, $p = 0.02$, $d = 1.02$.

The interaction between format and temporal presentation was significant, $F(1, 95) = 4.31$, $p = 0.04$, $\eta^2 = 0.04$, showing that the difference between animated and static graphic format was significant for the sequential, $F(1, 95) = 16.75$, $p < 0.0001$, $d = 1.30$, but not the simultaneous presentation, $F(1, 95) = 1.70$, $p = 0.19$, $d = 0.31$. There was no other significant interaction.

7. General discussion

The aim of this study was to investigate whether reducing the transient effect of animation, compared to the permanence of static graphics, would improve the performance of ten-year-old children learning a complex hand procedure task, tying nautical knots, from dynamic visualizations.

In Experiment 1, as predicted by *hypothesis 1a*, we found that animation was superior to static graphics for learning to tie complex knots. Furthermore, in the present experiment, this superiority of animation over static graphics was shown in an ecological learning task combining observation and practice. Learning times were also faster under the short-than long-section condition, and, as predicted by *hypothesis 1b*, the format*section length interaction showed that animation did not lose its superiority over static

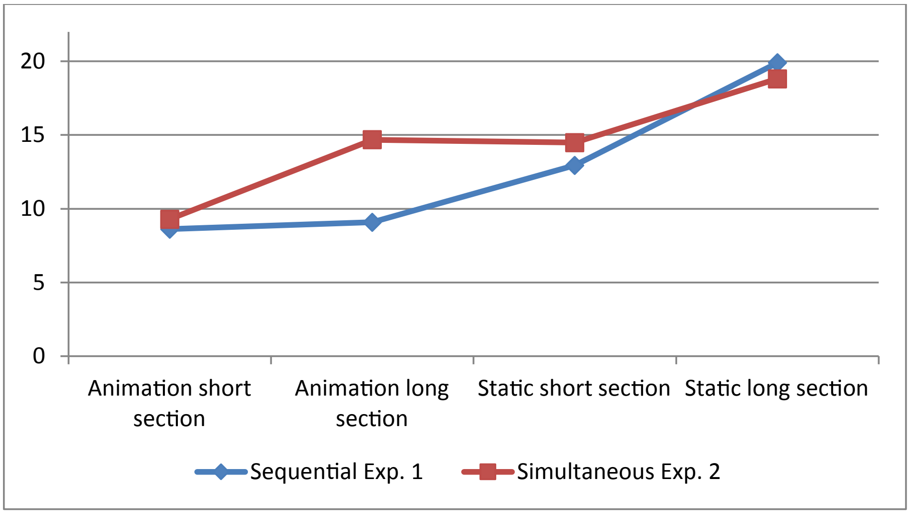

Fig. 5. Means of total learning time, for all knots, under each learning condition (Animated short section, Animated long section, Static graphics short section, Static graphics long section) for the sequential presentation of Experiment 1 and the simultaneous presentation of Experiment 2.

graphics under the long-section condition. The difference between short- and long-section presentations was not significant for animation. However, for static graphics, long sections resulted in poorer performance than short sections.

We believe that the results of the present study are still consistent with the cognitive load theory. In our task, the effect of section length was significantly greater for static graphics than for animation. In animation with short sections, not only does the amount of information not exceed working memory capacity, but the combination of observation and practice could provide meaningful cues (e.g. making a loop). This combination of observation and practice could compensate for the possible difficulty of integrating sections due to the fact that learners could not refer forwards or backwards to parts of the material. However, in our task, learners were allowed to repeat the presentation at will until they could correctly tie the knot. Even under the long-section animation condition, cognitive integration of the segments was thus still possible. However, this integration process might take longer with static graphics than with animation, because static graphics do not show the dynamics of hand actions.

Our results extend but differ from the findings of previous research. On the one hand, they are in line with a consistent body of research showing the superiority of animations and videos over static graphics in learning hand procedures (Ayres et al., 2009; Höffler & Leutner, 2007; Marcus et al., 2013; van Gog et al., 2009; Wong, Marcus, Ayres, Smith, Cooper, Paas & Sweller, 2009; and recently,; Brucker, Ehlis, Häußinger, Fallgatter, & Gerjets, 2015; see also the meta-analysis on the effect of animation over static graphics by; Höffler & Leutner, 2007, and by; Bernay & Bétrancourt, 2016). Furthermore, our findings indicate that this superiority of animation over static graphics can be extended to an ecological learning task combining observation and practice. On the other hand, our results differ from those of another group of previous studies, which showed that dynamic presentations could lose their superiority over static graphics with long-section animations (e.g., Wong et al., 2012).

It is possible that the cognitive integration of long-section static graphics requires resource-demanding processes, different from those related to transience, which may increase cognitive load. Whatever the length of the static graphics presentation, and even when the temporal distance between frames is small, relevant dynamics are not given and must be internally constructed from the series of static pictures. Mentally constructing internal dynamics from still pictures may be very resource and time demanding. Our task involved iterative alternations between observation and practice and was constrained by the strict temporal order of the task. As a result, under the static graphics conditions, especially with long sections, visual searching, comparison between frames, competition for attention, and inhibition of irrelevant information within and between pictures may have imposed a heavy load on the cognitive integration of the steps involved in tying the knots. These demands on perceptual and cognitive resources may be as strong as the demands related to transience effects. Future studies should examine this issue further, using eye tracking, for example.

By contrast, long-section animation provides relevant dynamic information step by step, so that relevant information is naturally cued at the right time, and in line with the perceptual salience of the required hand movements. The continuous hand movement events may have kept attentional continuity and helped learners to build and link events to form more super-ordinate structures and improve their comprehension and memory, in other words, turning patterns of hand movements into meaningful events (Huff et al., 2011). What we called above "*the attentional continuity effect*" of continuous animation, based on the "Attentional Theory of Cinematic Continuity" (AToCC, Smith, 2012; Smith et al., 2012; Berliner & Cohen, 2011; Germeys & d'Ydewalle, 2007; Smith, 2006) could explain part of the advantage of animated presentation. Furthermore, the nature of the task used in the present experiments, allowing learners to watch the animation repeatedly, together with the alternations between viewing and practice, may have compensated for the cognitive load of transience.

This interpretation seems to be supported by the results of Experiment 2, and also by comparison of the two experiments. First of all, in Experiment 2, animation was again superior to static graphics. Secondly, the only significant difference in learning times between Experiment 1 (sequential presentation of the sections) and Experiment 2 (simultaneous presentation) was under the long-section animation condition. With the conventional sequential presentation, participants needed the same time to learn the knots under the short- and long-section animation conditions. By contrast, with the simultaneous presentation, learning times were longer with long-than short-section animations, and the former lost its advantage over long-section static graphics. The simultaneous presentation of continuous short-section animations was predicted to reduce between-section transience. However, the results of Experiment 2 suggest that this type of presentation is inconsistent with the strong temporal constraints involved in learning manual tasks. In sum, simultaneous presentations of explanatory animations, which have been shown to encourage active comparison of steps and relational processing, thereby enhancing the extraction of higher order relationships (Ploetzner & Lowe, 2014), are not effective for learning hand procedures. In simultaneous presentations, the competition for attention between the animations, the additional visual searching between the small animations caused by the simultaneous displays, and the need to inhibit irrelevant but salient information may increase the demand on cognitive resources. In manual tasks, simultaneous presentation interferes with the need for sequential and time-locked presentation of the steps.

The possible difficulty of inhibiting irrelevant but equally salient information during observation and practice could explain certain learning difficulties. With simultaneous presentation, the difference between the short- and long-section animation conditions was revealing. Under the long-section condition, the animated sections were displayed simultaneously, whereas under the short-section condition, the final frame of each animated section remained on screen. In this way, the only animated image involved the current movement, but comparison between sections was still possible. There was thus optimal alignment between the perceptual salience of the information provided and its relevance to the temporal constraints of the task. Learning time under this condition was similar to that of the short- and long-section animation conditions of Experiment 1 (sequential presentation). In the simultaneous long-section animation, perceptual salience was neither aligned with, nor well attuned to the needs of the task.

8. Limitations and future work

The present research was limited to the learning time measure during the animated and static presentations. It would be interesting to test the possible effect of animated vs. static presentation of hand procedures on performance of a delayed recall test for the following reason. In the present work, we found that learning times were significantly different under animated and static conditions. Could these differences in learning time lead to differences in the strength of the traces left in longer-term memory and remain in a delayed post-test? It would also be useful in future studies to use eye movements to investigate further and in greater depth the perceptual and cognitive processes involved in learning manual skills from animations and static graphics (see Boucheix & Lowe, 2010; Boucheix et al., 2013; van Gog & Scheiter, 2010).

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