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Influence of 2D and 3D view on performance and time estimation in minimal invasive surgery

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This study aimed to evaluate the impact of two-dimensional (2D) and three-dimensional (3D) images on time performance and time estimation during a surgical motor task. A total of 60 subjects without any surgical experience (nurses) and 20 expert surgeons performed a fine surgical task with a new laparoscopic technology (da Vinci robotic system). The 80 subjects were divided into two groups, one using 3D view option and the otther using 2D view option. We measured time performance and asked subjects to verbally estimate their time performance. Our results showed faster performance in 3D than in 2D view for novice subjects while the performance in 2D and 3D was similar in the expert group. We obtained a significant interaction between time performance and time evaluation: in 2D condition, all subjects accurately estimated their time performance while they overestimated it in the 3D condition. Our results emphasise the role of 3D in improving performance and the contradictory feeling about time evaluation in 2D and 3D. This finding is discussed in regard with the retrospective paradigm and suggests that 2D and 3D images are differently processed and memorised.

Statement of relevance. This study reports a discrepancy in time estimation when subjects perform with a 2D or 3D vision. This type of study is relevant for ergonomics research and practice because it provides new data on the processing of central information (time estimation) in complex environment. With the introduction of new technologies, operators are more isolated and their temporal references could be disturbed, which may lead to some forms of human error (e.g. wrong estimation of the ongoing time by the surgeon and thus wrong communication with the anaesthetist about the intervention duration, with some harmful consequences on the anaesthesia management).

Keywords: 2D–3D images; time estimation; visuo-motor performance; new technology; minimal invasive surgery

1. Introduction

Time estimation is a crucial factor of adaptive behaviour. Indeed, timing is essential to ensure the optimal functioning of organisms. Awareness of temporal components of dynamic processes has been recognised as essential for control and situation awareness, and thus for safety (De Keyser 1995). However, humans are not always accurate in time estimation and intervals with identical stimulus durations are not always judged to be equal in perceived duration. Moreover, people actually evolve in a world where new technologies are more and more present, leading to changes that could affect the sense of time. Nevertheless, very few studies have investigated the impact of new technologies (e.g. virtual reality) on time estimation. In surgical context, control and thus awareness of time are particularly critical factors for patient safety and technical and organisational constraints (Nyssen and Javaux 1996). The purpose of this study was to evaluate how the use of new technology (and particularly, robotic surgery) affects the perception of time. More precisely, we aimed to investigate the effect of two-dimensional (2D) versus three-dimensional (3D) images on task execution speed and time estimation.

1.1. *Time estimation paradigms*

In the study of subjective duration, two paradigms are traditionally differentiated: the prospective paradigm, in which participants know in advance that they will have to judge the duration of a time period, and the retrospective paradigm, in which participants do not know until after a time period that they are being asked to judge its duration. In both cases, participants experience a time period in passing but the way in which they experience it and the various cognitive processes involved may nevertheless differ between the two paradigms (Block and Zakay 1997). In the prospective paradigm, a person may intentionally encode temporal information as an integral part of experience of the time period (the term *experienced duration* is used to refer to this paradigm, Block 1990). In the retrospective paradigm, a person may incidentally encode temporal information, and

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whatever information is relevant may be retrieved from memory later (the term *remembered duration* refers to this paradigm). These two types of duration seem mainly to rely on different cognitive processes: experienced duration is influenced by allocation of attentional resources to the processing of temporal information while remembered duration depends of amount and type of information stored and retrieved in memory. Thus, experienced duration seems to rely on attentional processes, while remembered duration is mainly explained by memory-based models (Block and Zakay 1997).

It is commonly assumed that non-temporal information processing differentially affects prospective and retrospective time estimations (McClain 1983, Zakay 1993, Zakay *e al*. 1994). Other differences, shown in the literature, are consistent with the notion that somewhat different processes underlie experienced and remembered duration: although both prospective and retrospective duration judgments tend to be underestimated, prospective judgments are longer (about 16% greater) than retrospective judgments and thus, are typically more accurate than retrospective judgments (for a review, see Block and Zakay (1997)). In addition, retrospective judgments show about 15% greater inter-subject variability than do prospective judgments.

Many studies used a prospective paradigm but relatively few have used a retrospective paradigm. The main reason for this imbalance is that, after a participant is asked to provide a retrospective judgment, the participant is then aware that he or she may be asked to judge a subsequent duration and the task becomes prospective (Block and Zakay 1997). Contrary to prospective paradigm where the experimenter informs participants beforehand they will be asked to judge time duration, our experimental protocol was based on the retrospective paradigm. In fact, our participants were not aware of the time-judging task and they were asked to judge event duration only after the time period had elapsed. Our objective was to study this unexplored retrospective process in a complex environment. Indeed, no widespread agreement exists on how to explain remembered duration. The greater inter-subject variability observed in retrospective judgments suggests that participants may use more varied processes to judge remembered duration (Block and Zakay 1997). For example, time duration seemed longer when subjects used different kinds of cognitive processes. The remembered duration of a time period is not simply a reflection of its actual duration (Avni-Babad and Ritov 2003). Early models suggested that retrospective evaluation was based on retrieval of information from long-term memory (Ornstein 1969). Events that occurred during the remembered period serve as markers for reconstructing duration: the more events remembered, the longer the judged duration (Predebon 1996). However, this storage-size model is not the determinant factor. It appeared that the most important factor in assessing duration was not just the number of recalled events but the extent to which those events constituted a contextual change (Block 1985). Cognitive research on the psychology of time showed that changes introduced during a time period influenced its remembered duration: remembered duration decreases if events or changes are fewer or more difficult to remember (Block and Reed 1978, Block 1978). The purpose of this paper was to study how new technology and particularly, images in 2D and 3D affects remembered duration in a complex environment with experts and novices.

1.2. *Context of the research: Minimal invasive surgery*

The context of our study was minimal invasive surgery and particularly, the robotic surgery. Laparoscopic surgery is a surgical technique performed with the help of a camera and long instruments introduced through small incisions into the body. Laparoscopic surgery brings a lot of advantages, particularly for the patient (very small incisions, smaller risks of infections, higher accuracy owing to the magnification by the camera, fast recovery). However, with this technology, the view of the surgical site is indirect and restricted, and the surgeon has to manipulate tissue and organs through very small incision with only visual feedback of the action. As the tactile and force feedbacks are lost in minimal-access surgery, the video image plays the most crucial role in giving the surgeon information about the performance of the operation. In classical laparoscopy, the surgeon looks at a 2D screen while the robotic system allows a 3D natural view integrated in a console.

A wide literature showed that image in 2D and image 3D do not contain the same information (Jackson *et al*. 1997, Bingham and Pagano 1998). Indeed, image in 3D contains more cues especially in order accurately and efficiently to guide the action. Although monocular cues compensate somewhat for the lack of depth perception in 2D view and are useful for some tasks (providing performances comparable than 3D view, e.g. in distance estimation, Falk *et al*. 2001, Servos 2000), monocular vision has been shown to particularly affect kinematics and pattern human motion. For example, in 2D view, subjects tend to underestimate object distance when performing reaching and grasping movements (Marotta and Goodale 1998, Servos 2000, Greenwald *et al*. 2005). According to the cognitive literature, surgical tasks should be performed better in 3D view than in 2D view. However, results about the benefits brought by the 3D vision are contradictory: some studies showing best performances with 3D vision (Birkett *et al*. 1994, Peitgen *et al*. 1996, Dion and Gaillard 1997, Van Bergen *et al*. 1998, Taffinder *et al*. 1999, Munz *et al*. 2004, Bhayani and Andriole 2005, Blavier *et al*. 2006) while others failed to obtain difference of performance between 2D and 3D view (Pietrabissa *et al*. 1994, Crosthwaite *et al*. 1995, Hanna *et al*. 1998). Divergence in all these results might be explained by different sources. The first one is that the tasks and their level of complexity varied considerably among the studies. Different studies (Birkett *et al*. 1994, Blavier *et al*. 2007) showed that difference of performance between 2D and 3D view depended of the task complexity. A second source of inconsistency is that the expertise of participants was different among the studies, some studies using medical students (Taffinder *et al*. 1999, Hubens *et al*. 2003) while others used expert surgeons (Crosthwaite *et al*. 1995, Hanna *et al*. 1998). One purpose of this study is to evaluate the difference between novices and experts while performing with a 2D or 3D view. A third source of discrepancy is that first-generation 3D systems, with their lower resolution, were compared with standard 2D systems (Falk *et al*. 2001). Some of these stereoscopic systems distorted depth images (Meesters *et al*. 2004) or stressed the visual system (Hoffman *et al*. 2008), eyestrain with former 3D systems was often reported by the participants in previous studies (Chan *et al*. 1997, Hanna *et al*. 1998). Our objective was to answer this debate and to evaluate the benefits of 3D vision in minimal access surgery using the da Vinci robotic system that allows quasi natural 3D visualisation of the operative field.

In summary, the present study aims to evaluate the impact of a new generation of binocular vision system on surgical task in order to clarify the debate about the gain of 3D view on 2D images in surgical tasks (by measuring task execution speed) according to the subject expertise. This is necessary to complete our main goal that is to study the impact of 2D and 3D performance on time estimation, hypothesising that 3D and 2D images will not have the same impact on remembered duration.

2. Method

2.1. Material

In our experiments, we used the Da Vinci system (see Figure 1). It consists in two primary components: the surgeon's viewing with a control console and a moveable cart with three articulated robotic arms. The surgeon is seated in front of the console, looking at an enlarged 3D binocular display on the operative field while manipulating handles that are similar to 'joy-sticks'. Manipulation of the handles transmits the electronic signals to the computer that transfers the exact same motions to the robotic arms. The computer interface has the capacity to control and modify the movements of the instrument tips by downscaling deflections at the handles by a factor between (5:1 to 2:1). It can eliminate physiologic tremor, and can adjust grip strength applied to the tools. The computer generated electrical impulses are transmitted by a 10 m long cable and command the three articulated 'robot' arms. Disposable laparoscopic articulated instruments are attached to the distal part

Figure 1. Da Vinci system.

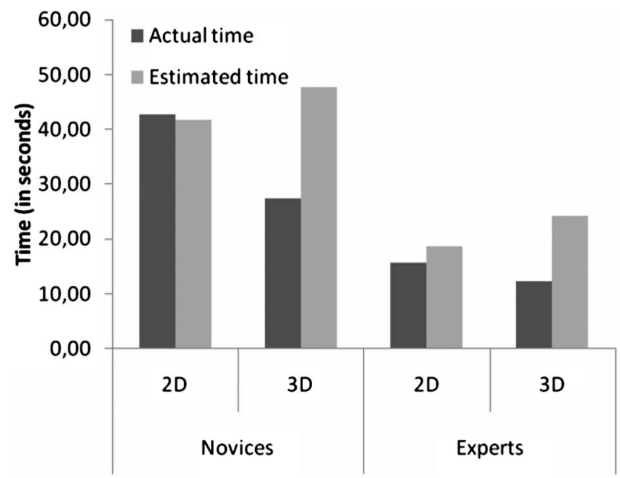

Figure 2. Actual versus estimated time according to the viewing condition.

of two of these arms and the third arm carries an endoscope with dual optical channels, one for each of the surgeon's eyes. The two cameras (one for each eye) generate two slightly different images as human stereoscopic vision and display depth naturally, without effects of image distortion or eyestrain. Moreover, the 3D visualisation with this system can be changed to 2D if desired (the 2D view is produced by displaying the same image for both eyes). In order to compare 2D and 3D with the exactly same system, we used 3D and 2D options in this study.

2.2. *Subjects*

We conducted our study with two different populations. One sample was constituted by surgeons (20 men) who were experts in minimal invasive surgery and who were used to perform with both 2D and 3D view. To avoid any bias from earlier laparoscopic experience, we selected another large sample of participants without any experience in open, minimally invasive or robotically assisted surgery. Sixty nurses (53 women and 7 men) without any experience in conventional, laparoscopic or robotic surgery participated. All subjects were randomly assigned to one of two conditions: one group (10 surgeons and 30 nurses) performing the task with the robotic system in 2D view and the other group (10 surgeons and 30 nurses) performing the task with the robotic system in 3D view option.

2.3. *Experimental task*

The task was chosen according to some basic surgical activities that consist in opening a tube and removing small piece from the tube (Bhayani and Andriole 2005). In our experiment, this task precisely consisted in displacing a plastic bead of five millimetres from a closed isolating tube to another one. The tubes were parallel and horizontally disposed at different depths (interval of 5 cm). This task did not involve any memory or attentional process but well visuomotor processes (eye–hand coordination with only visual feedback). The task did not require camera displacement, only manipulating instruments using both hands (one for opening the tube, and the other one for picking up the piece). Except the dimension view (2D versus 3D), all task and setting characteristics were identical in the two conditions. The participants were only explained how the system worked but they were not given any training prior to executing the task.

2.4. *Measures*

The time (in seconds) needed to accurately perform the task was recorded using a stopwatch. Time to achieve a task is not the only indicator of a good performance (even if it is often used in this way) but this factor remains crucial in surgical intervention management and in our study, it took into account the performance accuracy: longer was the time, worst was the accuracy. Immediately after performing the task, participants were asked verbally to estimate the time taken to execute the task. Their self-confidence and satisfaction about their performance were scored on a 4-point Likert scale (indeed, previous research showed more self-confidence and satisfaction with 3D view than with 2D view, which influences the well-being and the error management, Blavier *et al.* 2007a, b)

A ratio score (duration judgment ratio, Block *et al.* 1998) was calculated by dividing the estimated duration by the duration that has actually passed by. Thus, a value of 1 represents a perfect estimation (estimated duration = actual duration), values lower than 1 are indicative of an underestimation (estimated duration < actual duration), and values larger than 1 represent an overestimation of elapsed time (estimated duration > actual duration).

3. Results

A three-factor ANOVA was conducted with the type of duration as a within-subject factor (actual versus estimated time) and the expertise (experts versus novices) and the visual condition (2D versus 3D view) as two between-subject factors. As shown in Fig. 2, novice subjects were significantly faster to perform the task in 3D than in 2D (respectively, 27.45 $\pm$ 2.79 and 42.65 $\pm$ 2.66, $p < 0.01$), while no significant difference in time performance between 2D (15.72 $\pm$ 3.68) and 3D (12.28 $\pm$ 2.24) was observed in the experts group. Concerning subjective time estimation, all subjects in 2D vision accurately evaluated their actual time (novices: 41.76 $\pm$ 6.15; experts 18.58 $\pm$ 5.27) whereas subjects in 3D condition significantly overestimated their actual time (novices: 47.74 $\pm$ 6.44; experts: 24.15 $\pm$ 3.46, $p < 0.005$). Figure 1 illustrates this significant interaction between time estimation and actual time in function of viewing condition in both groups ($F(1,77) = 6.89$, $p < 0.05$). Calculated ratio also confirmed this effect by a ratio score of 1.06 $\pm$ 0.17 for novices and 0.95 $\pm$ 0.06 for experts in 2D condition, corresponding to quasi-perfect estimation, and a ratio score of 1.75 $\pm$ 0.13 for novices and 1.56 $\pm$ 0.22 for experts in 3D condition, subjective time estimation corresponding to almost twofold the actual time. Thus, although novice subjects showed significant faster performance in 3D than in 2D view and experts showed a similar performance in the two viewing conditions, all subjects estimated the duration of the task as (no significantly) longer in 3D than in 2D.

In the novice group, we also observed an unexpected interaction between time estimation and gender subject (see Figure 3, however, interaction did not reach significance because our sample contained few men, $F(1,58) = 3.39$, $p = 0.1$). Concerning the actual time, men and women showed similar performance. However, concerning the subjective time evaluation, men generally underestimated their time performance (ratio value lower than 1 = O.66 $\pm$ 0.28) whereas women tended to overestimate their time performance (ratio value larger than 1, ratio = 1.48 $\pm$ 0.13, $t(58) = 2.24$, $p = 0.05$). In 2D condition, ratio was similar in the two groups (1.1 $\pm$ 0.18 in women group and 0.71 $\pm$ 0.09 in men group) while in 3D condition, if the ratio sensibly diminished in men group (0.61 $\pm$ 0.06), it strongly increased in women group (1.87 $\pm$ 0.19).

Concerning self-confidence and satisfaction about their performance, experts felt significantly more confident and more satisfied than novices ($F(1,77) = 8.46$, $p < 0.05$) but no difference in both groups appeared either between the 2D and 3D conditions or between gender (see Table 1), contrary to other studies that showed higher self-confidence and satisfaction in 3D than in 2D (Blavier *et al.* 2007a, b).

4. Discussion

First, our study emphasises the important role of depth perception in surgery and the advantage brought by this new 3D generation in novice performance but not in expert performance. In fact, 3D view allowed a faster execution than 2D in a relatively simple motor task with novice subjects. Our results thus confirmed conclusion from other studies (Birkett *et al.* 1994, Peitgen *et al.* 1996, Dion and Gaillard 1997, Van Bergen *et al.* 1998, Taffinder *et al.* 1999, Hubens *et al.* 2003, Blavier *et al.* 2006) concerning the advantage brought by 3D in surgical tasks performed by novices. We showed no advantage of the 3D view over the 2D view in expert performance; indeed, surgeons are used to operate with a 2D view in classical laparoscopy and performed better than novices in 2D and in 3D. This finding suggests that surgeons have developed some mechanisms in order to compensate the loss of stereoscopic vision in 2D and to perform similarly in 2D and in 3D. Moreover, the task seemed very easy for the experts comparing to the novice group; we might have a difference between the 2D and 3D in expert performance with a more complex task. These results can partially explain the contradictory findings showing a difference between 2D and 3D in novice performance (Taffinder *et al.* 1999, Hubens *et al.* 2003) and not in expert performance (Crosthwaite *et al.* 1995, Hanna *et al.* 1998).

Concerning the time estimation, duration in 3D view was judged less accurately and longer (wrongly) than duration in 2D vision. It seems thus that images in 2D and 3D differently affect time evaluation. Different hypothesis could explain these results.

As our study used retrospective paradigm, subjects had to produce a remembered duration and thus to retrieve information in long-term memory in order to reconstruct the duration. For it, they had to use incidentally encoded temporal and non-temporal information (notably how they performed the task). Time judgments observed with retrospective paradigm, are principally explained by memory-based models. According to these models, the more events or more contextual changes remembered, the longer the judged duration (contextual-changes may arise from environmental events and from characteristics of the perceiver and the task, Block 1990). With the robotic system, the only cues available to remember duration

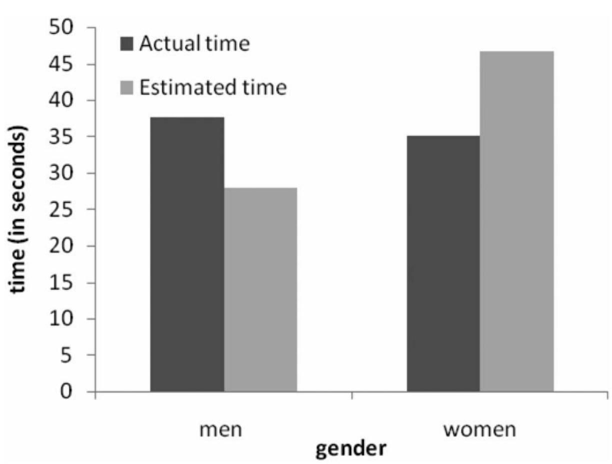

Figure 3. Actual versus estimated time according to the gender.

Table 1. Subjects' self-confidence and satisfaction about their performance.

	2D	3D
Self-confidence		
All subjects	2.26 $\pm$ 0.7	2.35 $\pm$ 0.6
Men	2 $\pm$ 0.33	2.67 $\pm$ 0.38
Women	2.3 $\pm$ 0.12	2.32 $\pm$ 0.12
Surgeons	4.21 $\pm$ 0.56	4.64 $\pm$ 0.43
Satisfaction		
All subjects	2.79 $\pm$ 0.64	2.77 $\pm$ 0.71
Men	2.75 $\pm$ 0.34	3.33 $\pm$ 0.39
Women	2.8 $\pm$ 0.12	2.71 $\pm$ 0.13
Surgeons	4.17 $\pm$ 0.35	4.39 $\pm$ 0.24

were essentially visual because of the lack of any other feedback. Memory of 3D or 2D events could be somewhat different and in consequence, have a different impact on time estimation. Moreover, greater stimulus complexity leads to increased remembered duration (Block and Zakay 1997). As in 3D vision, more cues are present, image in 3D containing more information could be more complex and thus the time could be judged longer. Another hypothesis could be that more kinds of cues and processes are used in 3D, leading to time overestimation comparing to 2D vision. A third alternative could be that with 3D image, subject could also encode a greater number of interpretations of the more complex image, leading to more changes in processing context (Block 1990). All these hypotheses could be also combined but they need further studies to be experimentally investigated with tasks of various levels of complexity and with the prospective paradigm.

Although our study was based on retrospective paradigm, subjects knew that the duration of their task execution was recorded. So they performed the task with a temporal constraint in mind. This instruction could have transformed our retrospective task in a prospective one because subjects may have paid attention to the speed. However, if they encoded some temporal information, it was incidentally because it was not requested. We can thus suggest that our study most likely used retrospective paradigm. Nevertheless, if we look at the results according to the prospective paradigm and biological clock or cognitive information processing models that explain this paradigm, we can hypothesise that performing task in 3D view, with more visual cues, requires less attentional resources than acting in 2D and thus allows to accumulate more information units concerning time duration, even if our task essentially required motor skills and not specific attentional or memory process (studies have shown that only memory tasks affected time estimation and that visual processing without any short-term memory involvement did not affect time processing, Fortin *et al*. 2005). Arguments in favour of this hypothesis come from recent studies that have shown that visuomotor system processes binocular cues faster than monocular cues (Greenwald *et al*. 2005). Furthermore, dissociation between prospective and retrospective judgments has not to be considered so rigid: indeed, attention could influence retrospective judgments, facilitating encoding and stocking information in memory (Zakay 2005).

Although literature reported time judgment underestimation and this, particularly in retrospective paradigm, we mainly obtained overestimation. This can be explained by our measurement method. Indeed, it is widely accepted that time judgments partly depend on the measurement method used (Brown 1985) and overestimations are more likely observed when the method of verbal estimation is used. We also observed a great variability in time estimation. Our findings confirmed thus that verbally estimated durations are usually long and particularly inaccurate.

Besides this important inter-individual variability, an unexpected result showed a (not significant) discrepancy between men and women subjective time estimation, with a particularly overestimation by women. Literature reports that gender constitutes a variable contributing to individual differences in estimation of time, even if the results concerning this contribution are quite confusing (Espinosa-Fernandez *et al*. 2003). Where differences were found between men and women, the general result has been greater precision and less variability in estimations of men, which corresponds to our findings (Block *et al*. 2000). Moreover, greater overestimation in the group of women is particularly observed when the retrospective paradigm and method of verbal estimation are used, as in our study (Kirkcaldy 1984, Block *et al*. 2000). The role of expectation constitutes another factor that could partly contribute to the difference between men and women in our results (Fraisse 1984). In our study, women expressed some particularly negative expectations about their performances in using this new technology and thus could overestimate the time needed to perform the task. This overestimation was particularly salient with 3D view because in this condition, time performance was really improved.

Finally, this task and the technology were new for all subjects. Nurses worked in operating room but they had never used surgical technology. Surgeons were used to accomplish this kind of task but were not used to manipulate this new surgical system. They had thus no possibility to base their time judgment on another similar experience. Moreover, we asked subjects to verbally estimate time in seconds or minutes, this metric and conventional duration unit is an externally and socially based code and moreover is not specific to work (De Keyser 1995). Indeed, several authors (De Keyser 1995, Nyssen and Javaux 1996) have shown that, in complex and dynamic work situations, expert operators base their time judgment and estimation not on the clock time (too expensive in cognitive resource) but rather on the contextual time (regularities, tasks order, events succession or simultaneity . . .). Further studies are needed to better understand the influence of 2D and 3D view on information processing and memory by using longer and more relevant tasks and other response modalities than verbal estimation.

In conclusion, with the new robotic system, surgeon is immersed in an augmented reality and loses his/her usual environmental cues to guide and manage his/her activity, with eventual perturbation of time estimation. This study constitutes a first step to better understand the difficulty for surgeon to manage operating time when using new immersive technology and thus the risk associated to error time management, for example for the anaesthesia duration (Blavier *et al*. 2005, Nyssen and Blavier 2006). It also showed that 2D and 3D images have different impact on motor performance but also on time processing, suggesting that 2D and 3D cues are differently processed.

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