Time perception is enhanced by task duration knowledge: Evidence from experienced swimmers

Simon Tobin · Simon Grondin

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Abstract The present study deals with the impact on temporal estimation of previous knowledge about the duration of a specific task (referred to as “task duration knowledge”). Athletes were recruited in this study because they are assumed to have high levels of task duration knowledge in their discipline. In Experiment 1, 28 elite swimmers had to estimate the time it would take to swim a given distance using two different strokes for which they had different task duration knowledge levels. The swimmers estimated duration more accurately and with less uncertainty in the high-knowledge than in the low-knowledge condition. In Experiment 2, the swimmers had to produce 36 s of swimming in various contexts that altered the retrieval of their task duration knowledge, with and without a secondary task. When swimmers could not rely on their task duration knowledge, their productions were more affected by the secondary task. In Experiment 3, the swimmers were more precise at producing time when visualising something that they knew well (swimming) rather than something that they had never experienced, which shows that physical execution is not a mandatory requirement for observing the enhancement effect resulting from task duration knowledge. These three converging experiments suggest that task duration knowledge is strongly involved in time perception.

Keywords Time perception · Memory · Attention

The past few years have seen a growing number of researchers putting forward the need to gain a better understanding

of the temporal properties of memory for time. As Taatgen and van Rijn (2011) recently summarised, almost every model of timing implies a memory component. However, this component has been understudied in the last few decades, as compared to other components or properties of timing models (e.g., the role of attention in the pacemaker–counter device). Nevertheless, some studies have focused on various aspects of temporal memory for time, such as the lifespan of memory traces (Gamache & Grondin, 2010); the interference between different temporal traces (Grondin, 2005) or between other task demands and memory traces (Ogden, Wearden, & Jones, 2008); the development of temporal memory (Rattat & Droit-Volet, 2005a, b, 2007); the effect of the number of presentations of a standard duration on temporal discrimination (Jones & Wearden, 2003); the influence of pharmacological substances on temporal memory (Meck, 1983); or the electroencephalographic basis of memory traces (Ng, Tobin, & Penney, 2011).

However, most of the abovementioned studies were conducted within the framework of scalar expectancy theory (SET) and/or used temporal discrimination tasks. Indeed, most tasks executed within the SET framework simply require the comparison of two (or more) very brief durations, as is the case with temporal generalisation, in which a participant must report whether a probe duration corresponds to a learned anchor duration (Grondin, 2010). Such a methodological paradigm is primarily used in SET because it is suitable for both animal and human research (e.g., Penney, Gibbon, & Meck, 2008). However, the results of studies using temporal discrimination may not apply to other, more complex time judgements, such as the verbal estimation of time. Indeed, Wearden and Lejeune (2008) concluded that “classical timing tasks” (e.g., verbal estimation and production) usually violate the scalar property of timing. Furthermore, Matthews (2011) recently concluded that verbal estimates of time may not be suitable for study of the properties of the internal clock (as defined by SET).

S. Tobin (✉) · S. Grondin
École de psychologie, Université Laval,
Québec, Québec G1V 0A6, Canada
e-mail: simon.tobin.1@ulaval.ca

S. Grondin
e-mail: simon.grondin@psy.ulaval.ca

Thus, when looking outside the temporal discrimination paradigm, the involvement of long-term memory (LTM) in timing still appears unclear.

While discrimination tasks only require a comparison between durations, other classical tasks, such as verbal estimation, imply the quantification of duration (e.g., in time units). Thus, not only is the judgement itself different, but the nature of the memory traces it generates may also be different. Indeed, when executing a daily activity (e.g., going from home to work), humans often get feedback in time units (i.e., the trip took 12 min today). Hence, humans may gain certain knowledge about the duration of a task. In turn, when they are asked to estimate the duration of this task, such knowledge probably plays a critical role. Unfortunately, the literature does not contain much information about the exact influence of such knowledge when time is estimated. Note, however, that developmental studies have shown that children as young as four already have representations of the duration of daily activities and are able to classify orderly daily activities (such as eating a cookie or watching a movie) on the basis of duration (Friedman, 1990). Furthermore, other studies (Burt, 1992, 1993) have suggested that people use general knowledge of specific events when asked to remember how long a past event lasted. Indeed, these studies have shown that participants could reconstruct the duration of an event by using global knowledge. As an example, when asked how long a previous pregnancy lasted, the global knowledge of “a pregnancy generally lasts 9 months” can easily be used to help remember the duration properly (Pyles, Stolz, & Macfarlane, 1935). Although the work from Burt is informative, it was more concerned with remembering an event’s duration and did not actually show how such knowledge is used to actively monitor time *during* the task at hand.

As many daily activities are executed routinely, they are subject to the learning of their duration. Indeed, it is well known that through the repetition of an action, one generates a script about the different components of that action. The duration of that action should be part of the script (see Schank & Abelson, 1977). However, even if the presence of such knowledge appears indisputable, its exact influence on time perception is still unclear. Nonetheless, some key experiments do seem quite relevant.

The effect of task duration knowledge on time perception

The following section will briefly report what is currently known about the influence of *task duration knowledge* on time perception. We will refer to this notion—*task duration knowledge*—as indicating any knowledge about a task’s duration that is stored in LTM. The key element is not the

familiarisation (or automatisisation) that occurs with task repetitions, but the fact that one extracts certain knowledge about the duration of the task. On the basis of Tulving’s (1985, 1986) model, such content in LTM is probably more (though not exclusively) specific to semantic memory, since the duration of a task is extracted from every occurrence of the task in the form of knowledge. Thus, if one is asked how long a specific task lasts, the knowledge (e.g., “5 min”) can probably be retrieved from semantic memory in a fashion similar to what would happen if one were asked to report one’s birth date.

Indeed, it is well known that verbal judgements about time (Hicks & Miller, 1976) and temporal production/reproduction (Fraisse, 1971) are improved with feedback. One way to account for this improvement is to posit that feedback contributes to task duration knowledge. Indeed, with repetitive feedback, participants gain critical knowledge about the duration of a task that can later be used for estimating time more efficiently. This point also suggests an important difference to put forward between temporal discrimination tasks and other classical timing tasks. Indeed, Jones and Wearden (2003) showed that varying the number of presentations of an anchor duration (one, three, or five times) did not improve temporal discrimination performance in a temporal generalisation task. However, temporal feedback quickly increases performance in quantification tasks. For instance, eight feedback trials (for each of three target durations) were enough to create a strong feedback effect for both verbal estimations and productions in Ryan and Robey’s (2002) study. Thus, the nature of a memory trace seems quite different, depending on the nature of the task, suggesting that caution should be taken when transferring findings from discrimination tasks to other quantification tasks.

One other interesting aspect of the feedback paradigm has been the addition of erroneous feedback, as this gives a strong insight into how task duration knowledge is used with regard to other timing processes. For example, Ryan and Robey (2002) conducted an experiment on both temporal production and verbal time estimation by comparing three feedback conditions: Feedback was accurate, systematically 20 % too short, or systematically 20 % too long. During the experiment, if participants in the “long” condition were asked to produce 10-s durations and actually produced them, they were told that the durations had lasted 12 s. The durations used for the study were 3.7, 5.6, and 8.5 s. During the pretest, the three groups had similar performance levels when it came to estimating time. During the testing phase, in which feedback was presented, each group modified their time estimations in accordance with the feedback. The “accurate” group became more accurate, while the “short” and “long” groups became systematically biased. In fact, the “long” group shortened their production by

20 %, while the “short” group lengthened their estimations by the same amount. The most interesting finding came from the posttest phase, in which all three groups were tested on the same task immediately afterwards, but without any feedback. Although the two erroneous groups had been similarly accurate in the pretest, they were systematically biased during the posttest: The participants tended to overwrite their initial good timing of the task (as shown in the pretest) by using the knowledge that they had gained during the feedback phase, even if it was wrong. Since participants had no task duration knowledge for the task during the pretest part of the experiment, their pretest performance can be seen as a reflection of their usual timing mechanism operating when no knowledge was available. However, once participants had learned erroneous knowledge, they were still influenced by it when feedback was removed. This suggests that the gained knowledge was preferred to the output of the timing mechanism that had been used in pretest (otherwise, participants would have returned to their pretest level during the posttest). This conclusion is critical, as it challenges our current understanding of time perception and requires further testing.

The “timing mechanism” that we have referred to as being used in pretest was probably attention-dependent. Indeed, a large body of studies have shown that attention to time is the critical aspect of time perception (see Block, Hancock, & Zakay, 2010). Hence, if one is interested in understanding how task duration knowledge is involved in timing, studying how it interacts with attentional demands appears to be a critical avenue. Attention to time-in-passing is probably the most studied mechanism in the field of time perception (Brown, 2008). It is well known that taking attentional resources away from time monitoring impairs time perception in prospective timing (Brown, 1997). *Prospective*¹ timing happens when participants are told before the start of a duration that a time judgement will be required, as opposed to the *retrospective* paradigm, in which participants are told only afterwards that the elapsed duration will have to be estimated (Tobin, Bisson, & Grondin, 2010). These two paradigms are important to dissociate, as prospective timing is said to rely more heavily on attention (Block & Zakay, 1997).

Most of the studies showing this critical role of attention in prospective timing have used a dual-task experiment (with one task being temporal and the other, secondary task being nontemporal). In such situations, the addition of the secondary task removes attentional resources from time monitoring, which impairs temporal accuracy (by quite

consistently shortening the perceived time). This phenomenon is referred to as the *interference effect* (Brown, 1997). Testing the effect of a secondary task in the presence of prior task duration knowledge should be very informative. Indeed, the results obtained with the erroneous-feedback method suggest that knowledge is primarily used, rather than the timing mechanism used during the pretest. If this conclusion is correct, the addition of a secondary task should have no (interference) effect on timing in a task for which there is high a level of task duration knowledge, while it should strongly affect a task for which no knowledge is available.

The present study

Although it seems simply logical that people would use their task duration knowledge (when it is available), current accounts of time perception do not take knowledge into consideration. Considering the putative role that task duration knowledge may play, it appears critical to address this issue. Furthermore, the reliance on task duration knowledge may prove quite relevant for many recurrent real-life timing situations, strengthening the need to investigate how this mechanism plays a role in time perception. Thus, the first goal of the following set of experiments was to assess the influence of task duration knowledge in different contexts (different temporal judgements, duration ranges, and tasks). Indeed, showing that task duration knowledge is consistently involved in numerous tasks should help draw attention to the topic. Our study also had another, more theoretical goal: determining how task duration knowledge operates and interacts with the attentional demands caused by the addition of a secondary task.

We chose to use ecological tasks, specifically, for two reasons. One was to show that the timing mechanism operates in “real-life” situations in which people gain and retain task duration knowledge on their own. The second, and more important, reason was to have access to strong task duration knowledge—that is, knowledge gained over a long period of time through extensive athletic training. Indeed, even though the erroneous-feedback paradigm is informative, the amount of knowledge that could be expected to be gained with feedback remains rather limited, when compared with an athlete’s knowledge. Furthermore, with the use of feedback, some confusion may arise regarding the source of the change that it does initiate. Feedback may produce a change only in the response rule (e.g., to shorten the time production), rather than in true learning about the durations that are presented. Thus, the participation of athletes seemed a very good way to assess the role of prior knowledge, as they have already gained the knowledge (and not a decision rule) before the experiment.

¹ The use of the term “prospective” may create some confusion if judgements are expected to be made prior to the task (as in a time prediction task), which was not the case here. Prospective timing is also different from prospective memory (see Graf & Grondin, 2006, for more on prospective memory).

Experiment 1

The first experiment targeted time estimation of long intervals (65–90 s) of swimming. Two main hypotheses were posited in this experiment. Firstly, higher levels of task duration knowledge should lead to more accurate time perception. Secondly, on the basis of Ryan and Robey's (2002) erroneous-feedback conclusions, a task involving higher knowledge levels should be less sensitive to the effect of a secondary task than would a task involving lower knowledge levels.

In the present experiment, we assumed that tasks involving intensive training would produce very high task duration knowledge. Over the years, elite swimmers such as the ones who participated in the experiment have trained to a level that could never be reproduced for experimental purposes in a laboratory. For example, a swimmer who has competed for 10 years (and trained around 20 h per week) will have completed about 750,000 pool lengths, with about 12,000,000 arm strokes, and will thus have accumulated thousands of temporal representations of the distance to be covered. In addition, swimming was chosen not only for its high training level, but also because competitive swimming involves four different strokes: butterfly, backstroke, breaststroke, and freestyle. Each swimmer specialises in one of these four strokes and tends to be weaker in one of them. The best stroke is usually a product of more training, and the weaker one a product of less. Therefore, the best stroke should produce a higher knowledge level than the weaker stroke, thereby allowing for the comparison of two different knowledge levels. Furthermore, even though one stroke is weaker, it remains an activity that is highly automatically executed. Therefore, both the best and the weakest strokes are executed automatically, with the result that the same attentional level is required for each one.

Method

Participants A group of 28 swimmers (18 male, 10 female) from the Laval University Varsity Swim Team were recruited. They ranged from strong provincial level to international level and were 18 to 23 years of age.

Material No specific material was used by the swimmers; they were instructed to approach the experiment as if they were doing a routine training session. Therefore, they all wore their usual training suits and accessories (goggles and swim cap). The university pool was set up as an eight-lane, 25-m pool; the deep side was used for the experiment, and the water temperature was 28 °C/82 °F. The pool's pace clocks were turned off throughout the experiment. An in-house questionnaire in paper form was used to test the

swimmers' knowledge about time (while swimming) and their experience as competitive athletes.

Procedure The swimmers were first instructed to fill out the questionnaire and were then given a free in-pool, 15-min warm-up session in which they were instructed to prepare as if they were going to compete. Following the warm-up, the swimmers were informed that they would have to estimate the time (prospective paradigm) that it would take them to complete each of four 100-m swims, executed in random order. Two of the 100-m swims were executed using their best stroke, while the other two were executed using their weakest stroke. In each case, the swimmers did the 100-m distance twice, once with an additional attentional demand in which they had to find words rhyming with a specific word (i.e., rhymes with “on,” like “lion”).² To ensure that the swimmers judged time as quickly as they could and had sufficient rest, they had to get out of the water after each swim to give their time judgements. They wrote their estimated time, as well as the minimum and maximum estimated time values (referred to as the *range interval*, or RI) on a piece of paper. The actual durations of the 100-m swim ranged from 66 to 112 s, with a mean of 83 s.

To ensure that the best/worst stroke manipulation achieved the expected goals, the swimmers had to quantify (on the paper form) the percentage of time they spent training with each stroke. On average, the swimmers claimed they trained 51.5 % of the time with their best stroke and 6.3 % of the time with their weaker one. To ensure that this difference translated into distinct task duration knowledge levels, the swimmers were asked how well they knew their training time for each stroke (from 1 to 5, with 5 being *very well*) and how confident they were about estimating their training time for each one. On average, they responded 3.92 and 3.50, respectively, for the best stroke and 1.92 and 2.21, respectively, for the weakest stroke. Paired-sample *t* tests revealed that the strokes differed statistically with respect to knowledge of training time, $t(27) = 11.72$, $p < .01$, and confidence in that knowledge $t(27) = 8.39$, $p < .01$. Therefore, different levels of task duration knowledge were associated with the two strokes, with better knowledge about duration being associated with the best stroke.

Results and discussion

Two dependent variables were used to measure the influence of these LTM knowledge levels on the accuracy of time estimation. The first one was the perceived-to-real time ratio (hereafter, simply the “ratio”). This variable is an indicator

² The experiment was conducted in French.

of estimation accuracy. Ratios of 1 indicate perfect estimations, whereas ratios below and above 1 represent underestimations and overestimations, respectively. The second measure was the absolute standardised error (ASE)—that is, the absolute value of the percentage of error. The values for these two variables in each experimental condition are reported in Table 1.

The first observation to be made about this experiment is that the swimmers were astonishingly accurate. Ratios so close to 1, as is the case here, are quite rare in the time perception literature. Hence, this impressive precision is a demonstration of the temporal expertise shown by athletes. It is important to keep in mind that, although swim time durations *in competition* are consistent (see Stewart & Hopkins, 2000), the time that it takes to swim 100 m *in training* is variable (e.g., for a 100-m freestyle, it can range from 55 to 85 s, depending on factors such as intensity and fatigue level). Thus, to perform this task, a unique duration could not be learned and simply retrieved. In these circumstances, ratios this close to 1 are quite impressive. As a basis of comparison, Yarmey's (2000) study had a condition with a similar mean duration of 1 min 15 s for a daily activity (using an ATM). Although the participants estimated time retrospectively in his study, the recorded time ratios were far from what we observed, with a mean of 1.28.

A 2 (stroke) $\times$ 2 (secondary task) within-subjects ANOVA was conducted on the ratio variable. Only the stroke effect was significant, $F(1, 26) = 25.74$, $p < .001$, $\eta_p^2 = .495$: The swimmers estimated time more accurately with their best stroke than with their worst one. The same ANOVA design, applied to the ASE, also revealed a significant stroke effect, $F(1, 24) = 10.46$, $p = .004$, $\eta_p^2 = .304$, with the swimmers making fewer errors when estimating swimming time with their best stroke. This confirms the hypothesis about the effect of task duration knowledge: Higher knowledge levels were associated with significantly more precise time estimations. Not only were the time ratios closer to 1 with the best stroke, but the percentage of errors (ASE) in this condition was significantly smaller. Indeed, not only was the

difference between the stroke conditions minimal (the ratio was only 0.037 away from 1 with the weaker stroke), but the interindividual variability was very low.

As for the hypothesis regarding the potentially stronger effect of attention with lower knowledge levels, none of the results were statistically significant. Two main aspects of the design may account for these nonsignificant results. Firstly, the secondary task (finding rhymes) may not have been sufficiently demanding to produce an effect (an issue that would be addressed in Experiment 2). Secondly, and more plausibly, the weak stroke was still too well trained, and thus provided sufficient knowledge levels to be unaffected by the secondary task. The second experiment was designed in part to address these issues.

The results for RI are also reported in Table 1. The same within-subjects ANOVA was conducted and, once more, only the Stroke factor was significant, indicating that the swimmers needed narrower RIs with their best stroke, $F(1, 25) = 7.24$, $p = .013$, $\eta_p^2 = .225$. These results are very interesting. Indeed, as we highlighted in the introduction, and as shown by the ratio and ASE results, it is now becoming clear that task duration knowledge improves performance accuracy in time perception tasks. However, no explanation has been offered as to exactly *how* it helps. The smaller RI could be a promising answer and an important theoretical contribution. Indeed, task duration knowledge might help estimate time by providing minimum and maximum time references. Later on, this duration range can be used to narrow the possible duration of the task down to somewhere between the minimum and maximum values, thus diminishing the probability of giving inaccurate time estimations. This hypothesis is in line with Yarmey's (2000) conclusions showing that invariable activities are estimated more precisely than variable (in terms of duration) activities. Indeed, as an activity's duration is consistent across times, it is easier to remember its duration, and thus to build a narrower RI around its consistent mean duration. This narrower RI facilitates time judgements, as the range of possible durations is narrowed. This idea is also coherent with one common finding observed with the feedback paradigm: Feedback does not reduce intrasubject variability in time judgements, but rather centers these judgements on the true durations (Ryan & Robey, 2002). Hence, task duration knowledge appears to help time perception by providing markers of what the real duration may be.

One of the immediate drawbacks of the experiment's design is that it involved the comparison of unequally trained tasks. Practice on a nontemporal task has been shown to reduce the amount of attention that it requires, hence increasing time perception accuracy (the attenuation effect; see Brown & Bennett, 2002). Thus, the best stroke may have involved more precise perceived duration because it was more intensively trained and required less attention.

Table 1 Mean (*M*) ratio, absolute standardised error (ASE, as %) and range interval (RI) as a function of stroke and secondary task conditions in Experiment 1

Stroke	Secondary Task	Ratio		ASE		RI	
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Worst	No	1.04	0.05	4.56	3.94	8.33	4.00
	Yes	1.04	0.06	5.31	4.38	7.43	3.18
Best	No	0.99	0.05	2.81	1.81	6.38	3.00
	Yes	1.00	0.04	2.62	1.91	6.66	2.54

SD is the standard deviation

Although logical, this explanation is quite improbable. First of all, as indicated earlier, both strokes, even the weaker one, were very well trained. The reported 6.3 % of training with the weaker stroke represents 765,000 arm strokes in a career. With this amount of training, it is most likely that the task was highly automatic (an idea shared by the swimmers) and did not require more attention to execute than the stronger stroke. The second experiment aimed at reproducing some of the previous findings with another time perception task (production). Also, it aimed at assessing the effect of a more demanding secondary task while addressing one of the first experiment's weaknesses (unequal training levels).

Experiment 2

For the purposes of this experiment, it was hypothesised that task duration knowledge should be context-dependent. For instance, a person could have high levels of knowledge about the travel from home to work; however, this knowledge is unlikely to be helpful if the person drives the same distance, but to a new location. This feature was used in this experiment with swimmers who were asked to produce certain durations of freestyle swimming in three retrieval contexts: regular, altered, and void. It was expected that swimmers would most likely use their knowledge about their speed and travelled distance to help them estimate time. Hence, these two parameters—speed and distance—were the ones altered in the experimental procedure. In the altered context, swimmers wore a piece of equipment to slow them down. Speed and distance information were still available, but it was not possible to swim at the usual, well-known speed. In the void context, swimmers were tied to the starting block by a stretch cord so that they couldn't use any information regarding their own movement. As a result, the swimmers in the regular context had full access to task duration knowledge; in the altered context, their task duration knowledge could be used, but with less accuracy; and in the void context, the same knowledge could not be used at all. However, from a technical standpoint, they all executed the same task: swimming freestyle for a targeted duration.

Two main hypotheses were posited. Firstly, given the results of Experiment 1, in the absence of secondary task, a higher level of task duration knowledge should lead to more accurate time judgements. Secondly, and most importantly, the more that the context is altered, the less knowledge can be used, and consequently, the more the addition of a secondary task should impair time production performance.

Method

Participants A group of 26 elite swimmers (18 male, 8 female) from the Laval University Varsity Swim Team

participated. Their expertise ranged from strong provincial to international level. They were 18 to 23 years old, and 19 of them had taken part in the first experiment.

Material The swimmers swam with their own usual training attire (swim cap, suit, and goggles). Two swimming training devices were used for the experiment. The first one, a commonly used swim training device, is called a “parachute.” It is a small piece of fabric (about one foot square) tied to a rope and belt around the swimmer's waist. It drags behind the swimmer, with the sole purpose of slowing him or her down. It does not interfere with the execution of movements. The second piece of equipment is a rubber stretch cord that is attached on one end to the swimmer's waist, and on the other at the pool starting block. A typical stretch cord usually allows strong swimmers to swim against resistance across the pool's 25-m length, but the one used in the experiment was shorter, to ensure that swimmers would not be able to move forward. The swimming pool was set up as an eight-lane, 25-m pool; the deep side was used, with a water temperature of 28 °C/82 °F.

Procedure Swimmers had to produce six times 36 s of swimming. These six productions were divided in three contexts: swimming normally (regular context), swimming with the parachute (altered context), and swimming tied to the wall by the stretch cord (void context). The duration production task was completed twice in each context condition, once normally and once in an attention-sharing condition in which a secondary task had to be completed during the swimming period. This secondary task consisted of counting backwards by a multiple (chosen randomly from the numbers 2 to 5) from a starting point (chosen randomly from 400, 500, 600, 700, 800, and 900). This task was chosen because it was expected to be more demanding than the rhyme task used in Experiment 1. All six productions were executed in a random order. The swimmers were instructed to instantly stop swimming when they thought that they had reached the 36-s target, wherever they were in the pool. At that moment, the time was stopped by the experimenter. After the production, the swimmers swam back to the starting end of the pool and had a rest period lasting between 30 and 60 s before the next trial (a sufficient rest for athletes at this level to avoid any fatigue effect).

Results and discussion

Ratio was selected as the dependent variable as it shows the direction of the error (over- or underestimation). Indeed, since the interference effect consistently affects temporal

perception in the same direction (i.e., lengthening the durations produced), a directional measure appeared appropriate.³ The mean values in each experimental condition are reported in Fig. 1. A 2 (attention) $\times$ 3 (context) within-subjects design ANOVA was completed on the ratio. The context effect was the only significant main effect, $F(2, 20) = 18.393$, $p < .001$, $\eta_p^2 = .402$, but it interacted significantly with the attention effect, $F(2, 20) = 6.432$, $p = .006$, $\eta_p^2 = .648$. Pairwise post hoc analyses revealed a significant effect of attention only in the void context: $t(21) = 3.048$, $p = .006$ (Cohen's $d = 0.987$). As well, in the absence of a secondary task, the only significant pairwise comparison was between the normal and modified contexts. In contrast, in the presence of the secondary task, all three contexts differ significantly from each other: The more modified the context was, the more inaccurate the production.

In the absence of the secondary task, the results partially confirmed the hypothesis. It was expected that the less altered the context, the better the production would be. The normal context was indeed the most precise, but it was not significantly better than the void context. Although surprising, this finding rules out the possibility that the difference observed with the secondary task could simply be explained by the novelty of the modified contexts, as there was no difference between these two context conditions without the secondary task.

Indeed, the impact of the secondary task differed in the various contexts, as was expected. Counting backward is a mentally demanding task often used as a secondary task (i.e., Prinz & Nattkemper, 1986; Sturman et al., 2007; Sturnieks et al. 2008). Although very demanding, it produced no interference effect in the regular and altered contexts. In contrast, the void context was strongly affected by the addition of the secondary task, as the ratio increased by 12 %. This differential effect of the secondary task based on knowledge levels strongly suggests a reliance on two distinct strategies. In other words, two distinct strategies might be at play: On the one hand, in the regular and altered contexts, swimmers relied on their task duration knowledge and tried to interpret contextual cues in accord with this knowledge. On the other, as they could not rely on task duration knowledge in the void context, swimmers decided to rely on chronometric counting, a strategy that proved to be effective, as they were as accurate as in the normal context (indeed, after completion of the experiment, many swimmers reported having used chronometric counting to help them perceive time adequately in the void context, explaining why their accuracy levels were similar to those in the normal context).

Fig. 1 Mean absolute standardised error (as a percentage) for each context, with and without the secondary task (ST), in Experiment 2. Bars represent 95 % confidence intervals

When swimmers relied on their task duration knowledge instead of on an attention-based strategy, they were not affected by the loss of attention to time caused by the secondary task. However, the secondary task strongly interfered with the timing strategy used in the void context. Indeed, as the secondary task forbids cognitive counting, swimmers were left with few attentional resources to perceive time adequately. Hence, the secondary task only produced an effect in the void context as that was the only context in which swimmers relied heavily on attention-based timing mechanisms. Somewhat along the same lines, Ryan and colleagues (Ryan et al. 2004) studied the effect of erroneous accuracy feedback when participants were instructed to use chronometric counting (and actual counts were recorded via keypresses). The results of the study showed that, when the strategies conflicted, participants relied on the information provided by the feedback rather than on their own counting. Furthermore, the counts recorded showed that participants had the same total of counts but modified the intercount interval to adjust for what was learned through feedback. Thus, that experiment also showed a dissociation between two timing sources, one memory-based and one attention-based, and suggests that memory-based information is used in priority over the cognitive timing strategy.

Experiment 3

The second experiment raised questions about the use of environmental cues. Indeed, one could argue that the effect obtained in Experiment 2 was only caused by the fact that the environmental context was poorer (i.e., contained fewer environmental cues, such as travelled distance and speed). This alternate explanation appears unlikely, as the normal and void contexts were perceived similarly in the absence of the secondary task. Thus, the addition of the secondary task proved to be the important factor, and not the richness of the context. Nonetheless, our next experiment was added in an

³ The analyses were also executed on the ASE. However, since the results were similar to those based on the ratio, it was decided not to report them.

attempt to evaluate the putative role of environmental cues—that is, how much the effect of task duration knowledge depends on the presence of contextual cues.

Swimmers were once again recruited and produced two visualisations of the same target duration from the second experiment (36 s). They simply had to visualise something they knew very well (swimming) and something they had never experienced (climbing Mount Everest). The key issue assessed here was whether swimmers can use their knowledge about swimming to help them perceive time, but without executing the movement. Thus, can they use that knowledge in the absence of any physical and environmental cues? It was expected that swimmers would be more accurate at visualising themselves swimming than climbing, thus showing that they can use their knowledge without any environmental cues. Such a finding would strengthen the claim of Experiment 2 by showing that the effect is not only dependent on environmental cues.

Furthermore, the use of the same target duration as in the second experiment allowed for a comparison between the physical and imagery variants of the same task (swimming). In that regard, it was expected that the physical execution (recorded in Experiment 2) would be more accurate than its visualised counterpart.

Method

Participants A group of 16 Laval varsity swimmers (12 male, 4 female) from 18 to 24 years of age participated in this experiment. They also ranged from strong provincial to international level. Six of them had participated in one of either Experiment 1 or 2.

Material Time was recorded with a Sanyo manual chronometer. A thin floor mat (yoga mat) was used for the swimmers to lie on during the experiment.

Procedure The participants were recruited prior to their training session. The experiment was conducted in a closed room adjacent to the swimming pool. The swimmers were instructed to lie on the floor mat with their hands on their chest. They were then instructed to visualise themselves for a 36-s target duration while they were (1) swimming in the university pool and (2) climbing Mount Everest. The two visualisation conditions were executed in a random order. The swimmers held the chronometer, face down, in their dominant hand and pressed the start/stop button themselves. A research assistant then recorded the visualised duration and reset the chronometer (the swimmers were not aware of their first performance before starting the second visualisation). Swimmers were instructed not to count mentally, only to visualise. They were also asked to keep their eyes closed.

Results and discussion

Ratios and ASEs were again calculated for the two produced durations. The results can be found in Table 2. Firstly, the ASE variable showed that swimmers were more precise (a smaller percentage of error) when asked to visualise themselves swimming than when visualising something they had never done. A dependent-samples *t* test was conducted and revealed that this difference was statistically significant, $t(16) = 2.69$, $p = .018$ (Cohen's $d = 0.56$). However, this difference did not translate into different ratios, as the values of this dependent variable were very similar for the two visualised tasks and did not differ statistically [dependent-samples *t* test, $t(16) = 0.11$, $p = .914$]. Thus, although swimmers were more erratic when visualising themselves climbing, their errors were not consistently toward under- or overestimation, thus explaining why the two tasks failed to differ on the ratio variable (under- and overestimations added up to a centered mean).

These results show that having task duration knowledge not only helps time perception while doing the task (as was shown in Experiments 1 and 2), it also helps perceiving time while visualising this activity; executing the movement is not mandatory for using the knowledge to enhance time perception. Indeed, when visualising, swimmers had no access to any external cues. Still, they were better (smaller ASE) at perceiving the time of something that they knew and had duration knowledge about (swimming) than at perceiving time on the basis of a motor task that they had never experienced (climbing). Thus, we can conclude that the performance-enhancing effect recorded in Experiments 1 and 2 was not caused only by the external cues related to their movement in the pool; the same kind of effect was obtained here without any physical movement.

The fact that this experiment used the same duration as in Experiment 2 also allowed for a comparison between physical execution and mental imagery. Thus, an independent-sample *t* test was conducted on the ASEs of the swimming visualisation and swimming in the normal context (without the secondary task). It shows that the produced time was significantly more precise when swimming the actual duration ($M = 7.10\%$) than when visualising it ($M = 12.51\%$), t

Table 2 Means and standard deviations (SDs) for ratio and absolute standardised error (ASE) in each of the visualised tasks of Experiment 3

Task	Ratio		ASE (%)	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Swimming	1.01	0.15	12.51	7.85
Climbing	1.01	0.21	17.81	10.79

(23) = 2.488, $p = .020$ (Cohen's $d = 0.83$). Thus, this experiment showed that time perception is better when visualising something known rather than something unknown, but it is still better to physically execute the action. One of the obvious reasons why the physical execution would be better than the visualisation is the presence of environmental cues. Indeed, when in the pool, swimmers get measures of their speed and movement that they cannot get while visualising. Although these environmental cues help time perception, they are not mandatory for seeing an effect of task duration knowledge, as swimmers were still better at visualising themselves swimming rather than climbing.

Also, while the main goal of this experiment was to assess the effect of environmental cues, the finding that visualising a well-known task helps time perception is quite interesting on its own. While many studies have compared the physical execution and visualisation of the same task (see Guillot & Collet, 2005), fewer studies have compared the visualisations of a familiar and a less familiar task. However, Decety, Jeannerod, and Prablanc (1989) found that participants were accurate when asked to visualise themselves walking a certain distance, but were less accurate when a novel requirement was added to the task (visualising walking the same distance while carrying a 25-kg weight on their shoulder). Thus, the familiarity of the visualised task plays a major role in its timing accuracy, be it the same task with different requirements (Decety et al., 1989) or two different (novel or well-known) tasks (Experiment 3).

Furthermore, in their review, Guillot and Collet (2005) concluded that mental imagery of a cyclic activity (like walking or swimming) was more accurately timed. Thus, the visualisation of repetitive movements (in this case, each swimming stroke) could serve as a way to segment the duration into smaller, more manageable time units. Indeed, there is consensus that chronometric counting helps perceiving time by segmenting the total interval into smaller time units (i.e., seconds; Grondin, Meilleur-Wells, & Lachance, 1999; Grondin, Ouellet, & Roussel, 2004). Thus, visualisation could be a similar way to improve time perception. Hence, in other timing tasks (unfamiliar tasks or tasks in which chronometric counting is forbidden), participants could be invited to visualise something that they know very well in order to help their timing performance. Thus, visualisation could prove a very effective way to enhance temporal performance in many situations in which timekeeping is required.

Finally, this experiment also raises a few fundamental questions. For instance, if knowledge can be extracted from movement, should this knowledge be self-related? As an example, if someone is told the average duration of a movement (instead of having experienced this movement), will she or he use that knowledge in order to make more precise time judgements? Studies on time prediction suggest that

this does happen. Indeed, by providing participants with an averaged duration of the task from previous participants, Roy, Mitten, and Christenfeld (2008) showed that having generic knowledge (i.e., not learned through personal experience) was sufficient to improve time prediction. Thus, the same pattern may apply to a time estimation or production task.

General discussion

The influence of task duration knowledge on time perception

The first goal of this set of experiments was to assess the influence of task duration knowledge on perceived duration. In that regard, the three experiments produced a coherent set of findings showing the influence of task duration knowledge on different tasks (time estimation and production) and durations (from 36 s to around 90 s). These converging conclusions strongly support the influence of task duration knowledge in timing.

Many studies have shown that giving performance feedback improves time perception accuracy. Indeed, feedback provides knowledge about the duration of the task, and this knowledge can later be used when participants are asked to estimate the duration of this particular task. This conclusion about the influence of knowledge can be drawn from various durations and various temporal tasks, such as verbal estimates (e.g., Hicks & Miller, 1976), production and reproduction (e.g., Fraisse, 1971), and temporal discrimination (e.g., Droit-Volet & Izaute, 2005). Our conclusion is quite similar to the one reported in these experiments, with the critical difference that we did not use feedback. Indeed, our participants had learned on their own the duration of the time that it takes them to swim a specific distance. Even so, we also observed the influence of knowledge on time perception in different tasks and durations. Thus, it now appears clear that task duration knowledge (whether gained naturally, through extensive training, or artificially, through feedback) serves to improve time perception performance up to an impressive level.

While it is clear that such knowledge improves time perception, less is known about how long that information stays in memory. A study by Rattat and Droit-Volet (2007) suggested that the retention delay is quite long. Indeed, they trained children to produce 5-s durations. Their participants were tested after a number of delays between the initial learning phase and the later test phase. Hence, the researchers found that even after a 6-month delay, children only 5 years old were still better than baseline (their performance level before the training session). To our knowledge, similar studies with adults and/or with longer delays are yet to be

done. However, the previous experiment suggests that the retention delay is very long.

Attention and memory

In order to integrate the notion of task duration knowledge with other pieces of information available in the timing literature, in the present article we questioned the relation between attention and task duration knowledge. For that purpose, the relative interference effect of a secondary task on different task duration knowledge levels was studied in both Experiments 1 and 2. Experiment 2 gave a critical insight into this topic. Indeed, the addition of a secondary task usually causes an interference effect—that is, a decrease in time perception performance (Block et al., 2010). However, when participants had access to their task duration knowledge in Experiment 2, the secondary task produced no interference effect, as their time production accuracy remained the same.

Although the interference effect is very robust, situations in which it has been smaller or absent (as observed here) have been detailed in the literature, and this is referred to as the *attenuation effect*—that is, the interference effect is attenuated (see Brown, 2008). For instance, by giving participants practice on the distractor task, Brown and colleagues (Brown, 1998; Brown & Bennett, 2002) obtained a reduction in the interference effect. More recently, Brown (2008) also observed an attenuation effect by giving participants some practice, but on a timing task, a design somewhat similar to the one we used in Experiment 2. Indeed, he compared the performance of participants in a dual-task situation, with one group having prior practice on the timing task with accuracy feedback, while the other group had the same practice without feedback. Participants who received feedback were less influenced by the secondary task, thus showing an attenuation effect. This finding is quite similar to the one obtained in our Experiment 2, with a few, key experimental differences. Indeed, as opposed to Brown (2008), participants in our design had gained their knowledge about the task naturally (without feedback) and were tested with a within-subjects design.

The classical attenuation effect (practice on the distractor) is generally explained by means of attentional processes. Indeed, as the participants are trained on the distractor task, its execution becomes automatised, and thus requires less attention, allowing more attention to be devoted to time. As for the attenuation effect obtained in our design (as well as the one obtained by Brown, 2008), we argue that it is better explained by memory processes (task duration knowledge). Indeed, our within-subjects design compared the same task (swimming freestyle), and the manipulation was only to impair proper retrieval of task duration knowledge. Thus, from the execution standpoint, the three contexts required

roughly the same level of attention. The same comment applies to Brown's (2008) experiment, since all participants had the same training level, although one group had feedback. Thus, we claim that the reliance on specific task duration knowledge, whether gained naturally (Experiment 2) or through feedback (Brown, 2008), explains the attenuation effect in these two experiments. What can be concluded from Brown's and our results is that in the presence of sufficient task duration knowledge, this knowledge can compensate for a decrease of attentiveness to time and can either rule out or attenuate the robust interference effect.

On a more theoretical note, the interaction recorded between attention and task duration knowledge is informative. The addition of a secondary task caused an effect only when no knowledge was available; time perception was not impaired when the same knowledge was available. Such an interaction is usually theoretically interpreted as a sign that two distinct mechanisms are at play. In other words, this finding suggests the presence of two distinct timing mechanisms, one knowledge-based and the other attention-based.

The attention-based mechanism is already well-known and has been described in the literature. Indeed, models like scalar expectancy theory (Gibbon, 1991; Wearden, Denovan, & Haworth, 1997) or the attentional gate (Zakay & Block, 1997, 2004) represent conceptualisations of a timing mechanism mainly based on attention that would operate in situations in which no knowledge is available (as in the void context of Experiment 2). However, the present results suggest that task duration knowledge can be responsible for a distinct timing mechanism that is unaffected (to certain level) by attentional demands. This idea is also in line with Franssen and Vandierendonck's (2002) conclusion that the effect of performance feedback is independent of attention. Indeed, they gave participants performance feedback in a dual-task condition in which the amount of attention to time that was allowed varied. Whether participants could allow all or just a few of their attentional resources to time did not interfere with the effect of feedback (the participants were more accurate with it). Thus, since the effect of feedback was constant across all attention levels (and not proportional to the amount of attention allowed to time), Franssen and Vandierendonck concluded that feedback was not simply a way to direct attention to time, but rather consisted of a distinct memory-related mechanism. Thus, acknowledging the presence of a knowledge or memory-based mechanism is a significant step towards a better understanding of the role of LTM in timing.

However, it also raises the challenge of determining how these two mechanisms interact. Indeed, the previous discussion may suggest that the two mechanisms are competing. However, they must probably be seen as two collaborating mechanisms trying to achieve the best result. Thus, to optimise the role of each mechanism, the interaction might

occur in many different ways, depending on the situation involved and on the amount of task duration knowledge available. For instance, in situations with very high task duration knowledge levels (e.g., when one has to estimate an invariable and well-known duration), the attention-based timing mechanism might be ignored, whereas in situations with no knowledge, the knowledge-based mechanism might be useless. Of even greater interest for future research are situations in which both outputs are used. With sufficient knowledge about the duration of a task, memory could modify or weight the timing outcome, making it more coherent with previously learned durations. Consider, for instance, a situation in which the attention-based timing output is 17 min, but the participant has learned an RI in which the task lasts from 19 to 23 min. To give a final estimation of time, the process could involve weighting the timing output in order to account for what has been learned through previous experiences with the task. In that case, the shorter timing output would indicate that the target duration was more likely to fall within the lower RI range, and thus would lead to the conclusion that the task lasted 19 min. Hence, the strength of the task duration knowledge could determine how much weight it has in the final time judgement.

Finally, the idea that knowledge could modify the initial timing output (or “internal feeling” about the duration) is coherent both with our finding of high knowledge levels being associated with smaller RIs (Experiment 1) and with Ryan et al.’s (2004) conclusion that participants modify their counting method (intercount interval) to adjust themselves to the erroneous feedback they have received.

Concluding comments

While there has been quite a bit of work on the knowledge about event durations when remembering these durations retrospectively (Burt, 1992, 1993; Burt & Kemp, 1991; Burt, Kemp, & Conway, 2001), not much information has been collected about the extent to which previous knowledge about the duration of a task influences duration estimations in the context of prospective timing. The present series of experiments has produced converging conclusions about the role of task duration knowledge on time perception when a participant is informed at the beginning of a task that estimating the duration of that task is required.

This series of three experiments consistently showed that task duration knowledge increases time performance, up to an impressive level, in a wide array of timing tasks. Furthermore, a few key theoretical contributions can be put forward after this investigation. First, Experiment 1 led to a hypothesis as to how task duration knowledge may help time perception: by providing a range of possible durations for each task that reduces the risk of error when having to

judge time. Furthermore, Experiment 2 showed an interaction between attention and task duration knowledge: The secondary task only interfered when swimmers could not rely on their task duration knowledge. This finding is crucial, as it suggests the presence of a distinct knowledge-based mechanism involved in time perception. Finally, the third experiment showed that the physical execution of the learned task was not mandatory for recording enhanced temporal performance. Not only does this finding strengthen the claims of the two previous experiments, it also suggests an innovative approach for supporting time perception. Indeed, visualisation of a well-known task or activity may act as a temporal performance enhancer in other, unfamiliar timing situations

Finally, we particularly would like to highlight the ecological properties of this set of experiments. As Tobin and colleagues have pointed out (Bisson, Tobin, & Grondin, 2012; Tobin et al., 2010), time perception studies are scarcely taken outside of laboratories. Indeed, this situation may remind one of Neisser’s (1976) call for a more ecological theory of the study of memory. In the case of task duration knowledge for prospective timing, ecologically valid investigations appear to be very appropriate, as the effect of task duration knowledge seems particularly relevant in the context of recurrent daily tasks. Though this ecological validity is an obvious strength of the present article, caution should be taken when interpreting the data, as the ecological aspect necessarily reduced the experimental control of some of the variables, mainly the exact contents of the participants’ task duration knowledge. Thus, further studies will be required for us to gain a more complete picture of the role of task duration knowledge in time perception.

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