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Underestimating the Duration of Future Events: Memory Incorrectly Used or Memory Bias?

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People frequently underestimate how long it will take them to complete a task. The prevailing view is that during the prediction process, people incorrectly use their memories of how long similar tasks have taken in the past because they take an overly optimistic outlook. A variety of evidence is reviewed in this article that points to a different, although not mutually exclusive, explanation: People base predictions of future duration on their memories of how long past events have taken, but these memories are systematic underestimates of past duration. People appear to underestimate future event duration because they underestimate past event duration.

Keywords: planning fallacy, memory bias, prediction, underestimation, time

People often underestimate how long it will take to complete a task. The Sidney Opera House took 16 years to complete instead of the 6 years originally planned (Hall, 1980). The Channel Tunnel between France and England and the Big Dig in Boston similarly, and famously, ran far behind schedule. On a much smaller scale, most are all too familiar with the paper that was supposed to be done in a couple of days but took a whole week to complete, or the home-improvement project that was planned for a weekend but took a month of weekends. This tendency to underestimate future task duration can lead to missed deadlines, cost overruns, and general aggravation. In a multibillion dollar business, such as software design, inaccurate estimations of completion time can prove to be extremely costly (Connolly & Dean, 1997).

The prevailing explanation of this tendency to underestimate is that people fail to use memories of how long similar tasks have previously taken. In contrast, but not to the necessary exclusion of the prevailing explanation, we propose, in what we term the *memory bias account*, that this tendency to underestimate future duration may be due to a tendency to underestimate past duration. People remember tasks as taking less time than they actually did and, therefore, underestimate how long similar tasks will take in the future.

First, we examine the evidence that there is a tendency to underestimate future duration in a review of studies in which future task duration is estimated. Second, we review current theories of why this tendency to underestimate occurs, including the most developed of these theories—the planning fallacy (Kahneman & Tversky, 1979, 1982). Third, we review the numerous attempts at improving accuracy of prediction as well as what they have in common and why they have been, for the most part, unsuccessful. Finally, we discuss the memory bias account; specifically, we examine a set of four predictions made by memory bias and the evidence in support of these predictions.

Evidence for the Tendency to Underestimate

Consistent with anecdotal accounts, a number of studies have found evidence for the tendency to underestimate the duration of future tasks. In this section we review, in chronological order, studies in which participants predicted future task duration and a comparison could be made to actual task duration. We located the studies with the *PsycINFO* database using keywords such as "time estimation," "future," and "planning fallacy." Studies found with this method were then used to locate additional sources. These studies are summarized in Table 1.

The studies listed in Table 1 included only published papers, which raises the possibility of a publication bias. However, it seems unlikely that this would introduce systematic bias. Because little is known about the ability to predict duration, any result—overestimation, accuracy, or underestimation—can be seen as interesting and informative. Also, as can be seen from Figure 1, there was quite a range of bias, positive to negative and small to large, in the reported studies. Additionally, as will be evident in the section on interventions used to try to improve prediction (Attempts to Improve Prediction Accuracy), there does not seem to be a bias in reporting results for cases in which the intervention was successful. If anything, these studies seem to show a bias toward a null result. Although it seems unlikely that using only published reports introduces bias in the results found here, the possibility cannot be ruled out.

A number of these studies were concerned with attempting to correct prediction (these attempts are detailed in Variables Affecting Memory, below). Note that the averages in estimated and actual duration in Table 1 are across all experimental conditions in each study. Given that the focus of a number of the experiments was to lessen the tendency to underestimate, this makes the overall tendency to underestimate all the more compelling.

In one of the first studies examining predicted duration, Koneçni and Ebbesen (1976) examined the estimated time spent in line for

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Table 1
Overview of Studies Examining Estimation of Future Duration

Study	No. of participants	Task	Actual task duration	Estimated task duration
Koneçni & Ebbesen (1976)	89	Wait in line for gas	28.8 min	19.0 min[a]
Buehler, Griffin, & Ross (1994)	37	Complete honors thesis	55.5 days	33.9 days[a]
	108	Complete academic task of participants' choice	9.2 days	5.0 days[a]
		Complete nonacademic task of participants' choice	10.7 days	5.8 days[a]
	78	Complete academic task of participants' choice	7.1 days	6.0 days[a]
	123	Complete computer assignment	6.7 days	5.9 days[a]
	123	Observers predict computer assignment for others	6.5 days	8.8 days
Burt & Kemp (1994)	100	Purchase a stamp at the bookstore	0.7 min	2.0 min
		Find a book in the library	4.2 min	10.0 min
		Fill out a biographical form	1.2 min	5.0 min
		Sort deck of cards	0.9 min	3.0 min
		Walk a specified distance	2.3 min	2.2 min[a]
	50	Proofread an essay	11.5 min	15.0 min
		Fill out a balance sheet	9.3 min	15.0 min
		Check out a book from the library	12.2 min	14.0 min
		Write a letter	10.2 min	10.0 min[a]
		Purchase a candy bar	7.2 min	7.0 min[a]
Buehler, Griffin, & MacDonald (1997)	79	Complete tax forms	14.2 days BDL	22.8 days BDL[a]
	60	Complete anagram-like word puzzle	6.4 min	6.3 min[a]
Byram (1997)	20	Build a computer stand	70.5 min	45.0 min[a]
	181	Make an origami object	8.0 min	6.0 min[a]
Connolly & Dean (1997)	35	Complete computer programming assignment	11.1 hr	9.1 hrs[a]
	24	Complete computer programming assignment	≈11.0 hr	~11.2 hr
Boltz, Kupperman, & Dunne (1998)	36	Perform a piece of music on the piano	3.1 min	3.5 min
Taylor, Pham, Rivkin, & Armor (1998)	84	Complete academic task of participants' choice	71% finished late[a]	
Francis-Smythe & Robertson (1999)	51	Proofread an essay	5.8 min	5.0 min[a]
Griffin & Buehler (1999)	215	Complete academic and nonacademic tasks of participants' choice	60% finished late[a]	
Hinds (1999)	96	Predict time on cell phone task for average novice	31.5 min	18.5 min[a]
	49	Predict time on Lego task for average novice	12.5 min	10.7 min[a]
Koole & Van't Spijker (2000)	120	Write an essay	1.9 days	1.3 days[a]
Newby-Clark, Ross, Buehler, Koehler, & Griffin (2000)	81	Complete academic task of participants' choice	0.01 days BDL	1.4 days BDL[a]
	109	Complete academic task of participants' choice	1.0 day BDL	1.8 days BDL[a]
	100	Complete academic task of participants' choice	0.7 days BDL	1.8 days BDL[a]
	98	Complete tax forms	12.1 days BDL	15.5 days BDL[a]
	98	Observers predict completion of tax forms for others	12.1 days BDL	13.2 days BDL[a]
Buehler & Griffin (2003)	78	Complete Christmas shopping	22.9 days	20.4 days[a]
	125	Complete academic task of participants' choice	16.6 days	15.0 days[a]

Note. BDL = before deadline.
[a] Indicates underestimation.

gas during the gas shortage of 1974. People waiting in lines that ranged between 9 and 23 cars were asked to estimate both the number of cars ahead of them in line and how long their wait would be. Although participants actually overestimated the number of cars ahead of them, they drastically underestimated how long it would take to get gas, thinking that it would take about 1 min per actual car ahead (30 s per estimated car) when in actuality it would take 3.5 min per car.

Buehler, Griffin, and Ross (1994) performed the first extensive research on the tendency to underestimate future duration. In their first study, undergraduates estimated when they would finish their honors thesis. On average, participants underestimated their completion time by 39%. For Study 2, participants made predictions for an everyday, nonacademic task (i.e., writing a letter to a friend) and an academic task (i.e., completing an essay) that would be finished within the next week. Participants, on average, underestimated how long it would take by 46%. Study 3 again had participants estimate how long it would take to complete an academic task that they planned to finish in the next 2 weeks using a think-out-loud procedure. After 2 weeks, only 70% of participants had actually completed the task, and of those that did, duration to finish was underestimated by 15%. An analysis of their spoken thoughts during planning indicated that most participants thought mostly of future plans while forming their estimation. For Study 4, participants were asked to estimate when, in comparison with the deadline, they would complete a 1-hr computer tutorial program. Overall, participants underestimated when they would finish the task by 12%. The final experiment had observers predict

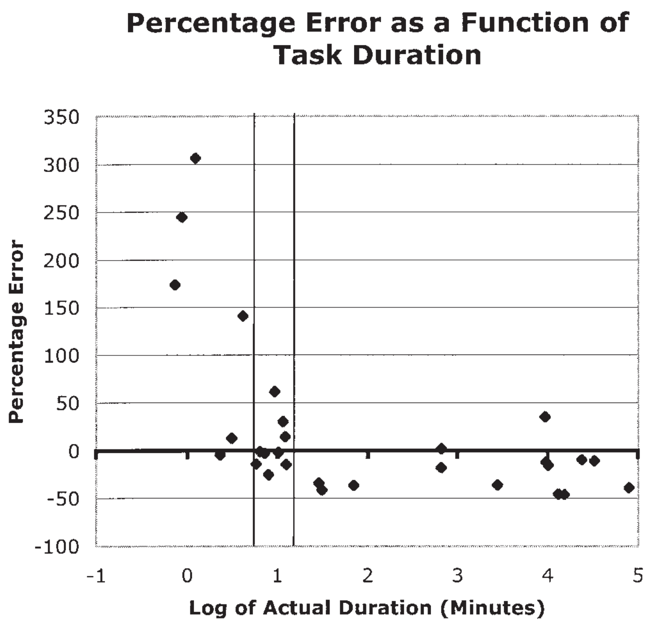

Figure 1. Signed percentage error—[(estimated duration − actual duration)/actual duration] × 100—for predicted future task duration as a function of task duration (log base 10 of actual duration).

how long they thought it would take for a portion of the participants in Study 4 to complete their task after reading material written by the previous participants. Unlike the actors, the observers tended to overestimate how long it would take the actor to finish by approximately 31%.

In one of the few studies to consistently find overestimation of future task duration, Burt and Kemp (1994) had students estimate how long it would take them to perform a number of short tasks performed on campus. In Study 1, participants estimated how long it would take to purchase a stamp (median actual duration of 0.7 min), look up and find a book in the library (*Mdn* = 4.2 min), fill out a biographical form (*Mdn* = 1.2 min), sort a deck of cards (*Mdn* = 0.9 min), and walk a specified distance on campus (*Mdn* = 2.3 min). The first four tasks were overestimated by 174%, 141%, 306%, and 245%, respectively, and participants slightly underestimated the duration to walk a specified distance by 4%. In the second experiment students were asked to estimate duration to perform a number of slightly longer tasks, but this time they were asked to indicate on a 60-min timeline how long it would take to perform five separate tasks. Participants overestimated the time to proofread a 6-page essay by 30% (median actual duration of 11.5 min), fill out a balance sheet by 62% (actual *Mdn* = 9.3 min), and check out a book from the library by 14% (actual *Mdn* = 12.2 min) and slightly underestimated the duration to write a letter by 2% (actual *Mdn* = 10.2 min) and purchase a candy bar by 3% (actual *Mdn* = 7.2 min). Here, however, the tendency to overestimate may be due to the methods used. Participants were told that the experiment would last 60 min and that they should try to do as many of the five tasks as they could. It could be that the participants used their knowledge that the experiment would last 60 min to anchor their prediction and merely partitioned that time between the different tasks. In fact, this is what the participants appeared to do, as most (43 out of 50) predicted that the tasks would take up the complete 60 min.

Buehler, Griffin, and MacDonald (1997) examined the effects of motivation for quick completion on time estimation. In the first study, participants predicted that they would send in their tax forms earlier than they actually did, with participants expecting a refund showing more bias (predicted *Mdn* = 27.6 days before deadline, actual *Mdn* = 15.2 days before deadline) than those not expecting a refund (predicted *Mdn* = 16.9 days before deadline, actual *Mdn* = 12.9 days before deadline). In the second study, participants performed an anagram-type task in which they had to construct smaller words from one larger word. Participants performed timed practices and were given feedback on their completion times for each, after which a portion of participants were offered monetary incentive for quicker completion times. Participants offered money to finish more quickly underestimated task duration by 9% in comparison with participants not offered the incentive, who overestimated task duration by 5%.

Byram (1997) examined the efficacy of a number of interventions in eliminating the tendency to underestimate, including decomposition of the task, listing possible surprises, creating multiple scenarios, and predicting as an observer. On average, participants building a computer stand underestimated how long it would actually take by 36%, with no effect of any of the debiasing techniques. A second set of experiments examined the effect of motivation on estimated duration to perform an origami task. Results from two experiments indicated an overall tendency to underestimate duration for the origami task by approximately 33%, and as with the Buehler et al. (1997) study, underestimation was greatest when monetary incentives were involved.

In a study concerned with variability in estimation of future task duration, Connolly and Dean (1997) had students in a programming class predict duration for a class project. Students made a series of five predictions of how long it should take if progress is fast (duration such that the task would be finished faster only 1% of the time) up to if progress is very slow (duration such that the task would be finished faster 99% of the time) for both the whole task and for the subcomponents of the task. For the whole task, which lasted approximately 11 hr, participants underestimated by an average of 18%, and the range of prediction between slow and fast scenarios was too small. In a second experiment using similar tasks, participants were asked to come up with scenarios of how similar tasks could take much longer or shorter than planned before estimating task duration. Here the range of their predictions was expanded, and when participants then predicted how long it would take to complete the computer programming assignment, the tendency to underestimate was eliminated.

In an experiment examining the effect of level of experience with a task on estimation, Boltz, Kupperman, and Dunne (1998) had pianists estimate how long it would take to play a piece of music with an average performance duration of 3.1 min that was either recently learned (average of 4.1 hr of practice), well learned (14.6 hr), or extremely well learned (34.6 hr). Participants overestimated the recently learned and well-learned songs by 48% and 11%, respectively, but underestimated the duration of extremely well-learned songs by 19%.

Taylor, Pham, Rivkin, and Armor (1998) examined the effect of using mental simulations to bring behavior in line with prediction. Students predicted when they would finish a school project that was due within the next week. A portion of the students were asked to spend 5 min each day either envisioning the steps that they would need to do to complete the task or envisioning their satisfaction in finishing the project. The majority of participants underestimated their completion date, but this effect was lessened by the use of mental simulation. Overall, 41% of participants who imagined the procedural steps finished by their predicted date, 33% of participants who imagined their success finished by their predicted date, and only 14% of participants who did not use either mental simulation finished by their predicted date.

Underestimation of task duration was again found in a study by Francis-Smythe and Robertson (1999) for students performing a spell-check task. Participants were asked to estimate in seconds how long it would take them to proofread a single page of text. On average, participants underestimated how long it would take by 14%.

Griffin and Buehler (1999) looked at the tendency to underestimate from a different angle. They were concerned with whether looking at events in terms of individual probabilities or in terms of aggregate frequencies would have an effect on estimation. In two of the studies, participants picked 10 school or personal tasks that they would be finishing in the next few months and predicted when they would be finished. Then they assigned individual probabilities to finishing each of the tasks by that time (individual probability) or they estimated how many of the 10 projects would be finished by the specified dates (aggregate frequency). In a third study, participants picked one task and, after predicting when it would be finished, assigned a probability that it would be finished by that date or estimated how many of 10 similar tasks would be finished by that date. There was no difference between estimates made by use of individual probabilities and aggregate frequencies, with participants in both conditions estimating that approximately 70% of their projects would be finished by their predicted date. However, participants completed only 40% of their tasks by the specified date.

Hinds (1999) was concerned with accuracy of predictions of how long it would take others to perform a certain task. People with varying levels of experience with either a cell phone task or a Lego toy task predicted how long it would take a novice to perform that same task. Overall, participants underestimated the time that it would take a novice by 41% for the cell phone task and 14% for the Lego toy task. The tendency to underestimate was greatest for participants who had a high level of experience with the task.

Koole and Van't Spijker (2000) examined the effect of implementation intentions (Gollwitzer, 1999; Gollwitzer & Brandstatter, 1997) on estimation and task completion. Like Taylor et al. (1998), the experimenters were interested in bringing behavior in line with prediction. They assigned participants an essay that they were to complete within the next week. All participants were asked to estimate when they would complete the task. Additionally, a portion of participants formed implementation intentions by stating where and when they would perform the task and visualizing themselves in that situation. Overall, participants underestimated how long it would take them to complete the task. Students in the implementation intention finished their project closer to their predicted completion time than did students who did not form implementation intentions, underestimating actual duration by 16.7% rather than 42.4%.

In a study concerned with the effect of forming a number of different scenarios on prediction, Newby-Clark, Ross, Buehler, Koehler, and Griffin (2000) had participants form different scenarios that varied in level of optimism and pessimism for either a school task due within 3 weeks (Experiments 1 to 3) or completion of their tax forms (Experiment 4) before giving their final prediction. Participants finished their school assignments approximately 1 day later than planned and their tax forms approximately 3 days later than planned regardless of the type or number of scenarios formed before prediction.

Buehler and Griffin (2003) found that focusing on future plans exacerbates the tendency to underestimate future duration. A portion of their participants were asked to come up with detailed plans of how they would complete either their Christmas shopping (Study 1) or a school project (Study 2) before they predicted how long before the deadline they would finish the task. All participants, regardless of whether they made detailed plans, underestimated when they would be finished, 4 days later than planned for Christmas shopping and 1.7 days later than planned for their school assignment, with underestimation greatest for participants who formed detailed future plans.

The tendency to underestimate seems to be a very general phenomenon found with quite different types of tasks. Almost all of the studies reviewed found a sizable tendency to underestimate. There were some tasks, however, in which there appeared to be a tendency to overestimate duration. Burt and Kemp (1994) found overestimation for fairly short tasks such as buying a stamp or looking up a book in the library, and Boltz et al. (1998) found overestimation for playing a less familiar piano piece. So, although there is an overall tendency to underestimate, there appear to be systematic shifts in this bias. In Figure 1 these trends become clear when signed percentage error is plotted as a function of the task duration. The studies shown here represent the tasks in which estimated duration and actual duration were assessed (this excludes studies in which results are given in term of duration before deadline or percentage of participants who completed the task by the assigned date). Signed percentage error is calculated by dividing the difference between estimated and actual duration by the actual duration and multiplying by 100. Given the large positive skew in the actual durations of the task, signed percentage error is plotted as a function of base-10 logarithm of actual task duration. Figure 1 has been broken into three sections on the basis of the likelihood of underestimation or overestimation. Tasks with a duration of less than 5 min (log 0.7) were more likely to be overestimated: Of six data points in this range, one is an underestimation of 4.3% and five are overestimations ranging from 12.9% to 244.8%. Tasks ranging between 5 and 12.5 min (log 0.7–1.1) appeared as likely to be overestimated as underestimated, with three overestimations of between 14.5% and 61.6% and six underestimations of between 0.9% and 14.4%. Tasks over 12.5 min were more reliably underestimated; only 2 of the tasks were overestimated, by 1.8% and 35.4%, and 12 were underestimated by between 9.7% and 45.8%. Although it appears that there is a tendency to underestimate task duration, this tendency is not ubiquitous. Short tasks, those less than 5 min, are more likely to be overestimated.

There are additional differences between the shorter tasks and the longer tasks. The majority of the short tasks took place in the lab and were uninterrupted from beginning to end (Boltz et al., 1998; Byram, 1997; Francis-Smythe & Robertson, 1999), whereas the longer tasks often used longer real-world tasks that contained intervening events before task completion (Buehler et al., 1994, 1997; Buehler & Griffin, 2003; Connolly & Dean, 1997; Griffin & Buehler, 1999; Koole & Van't Spijker, 2000; Newby-Clark et al., 2000; Taylor et al., 1998). The second sort of task is more complicated in that many factors—such as task duration, individual level of procrastination, and duration of intervening events—must also be considered. For the longer tasks, the estimates are generally about what day they think the task will be finished, whereas for the short tasks, the estimates are in terms of minutes and hours of task duration. It may be that predicting when a project will be finished is different from predicting how long it takes to perform the task (Buehler & Griffin, 2003).

Even though the tasks seem to be of two quite different sorts, there is a similar tendency in underestimation for both, and several studies suggest it is reasonable to regard them as similar. Buehler et al. (1997), for example, found a similar effect of motivation on estimation for both types of tasks. Treating both types of tasks as similar also receives support from work on retrospective memory for duration of autobiographical events. Burt (1992) had participants give retrospective estimates of duration of events taken from their diaries. He compared estimates of solid events with ones marked by a beginning and ending point but containing intervening events. For instance, the period of visiting home for the holidays is a solid event, whereas the period of purchasing a ticket over the phone and then receiving the ticket contains intervening events. Here, no difference was found between estimations of solid events and events that contained intervening events.

Current Explanations for the Tendency to Underestimate

Studies that have attempted to increase the accuracy of prediction supply possible explanations for the tendency to underestimate future task duration. These attempts will be described in detail in the following section. The majority of these studies focus on information in memory that may be ignored or incorrectly utilized. The assumption is that people (a) fail to remember that in the past they have been interrupted by surprises (Byram, 1997; Hinds, 1999), (b) do not remember all the subcomponents of the task when planning (Byram, 1997; Connolly & Dean, 1997), (c) are overly narrow in their focus on the task (Buehler et al., 1994; Byram, 1997; Connolly & Dean, 1997; Hinds, 1999; Newby-Clark et al., 2000), and/or (d) disregard memories of how long similar tasks have taken in the past (Buehler et al., 1994; Hinds, 1999). A possible culprit for this underutilization of memory is people's optimism regarding the particular task. People want to believe that the task will go as well as possible and that no problems will arise (Armor & Taylor, 1998).

The idea that optimism causes systematic problems in prediction is intuitive and falls in line with other research that finds a tendency to be overly optimistic in many domains (Armor & Taylor, 2002). For instance, students believe that they will receive better grades than they actually do (Shepperd, Ouellette & Fernandez, 1996) and believe they are less likely than others to suffer from health problems (Weinstein & Klein, 2002).

The tendency to be overly optimistic and to fail to correctly use memory during prediction are part of the planning fallacy as first developed by Kahneman and Tversky (1979, 1982). This is the best developed of the various explanations of underestimation behavior in which certain aspects of memory are disregarded.

The planning fallacy is the tendency to be overly optimistic about how long it will take to perform a task in the future, even though people are aware that in the past they have not finished our tasks by the predicted time (Kahneman & Tversky, 1979, 1982). People know that their past projects have taken longer than planned, but this has little or no effect on future planning.

Kahneman and Tversky (1979, 1982) suggested that there are two types of information that a person can use to make a prediction: singular and distributional. *Singular information* involves thinking only about the task at hand and how it will be completed in the future. *Distributional information* takes into account the past completion times of similar projects. They attributed distortions in future estimation to overreliance on singular information at the expense of distributional information. When predicting the duration of a future task, people form a single, optimistically biased scenario of how they think the task will be completed. This leads to underestimation in two ways: First, people ignore the actual past duration of similar tasks and base predictions on their optimistic view of when it will be finished. Second, people do not take into account the fact that there may be surprises or disruptions that could take place when they are trying to complete a task, even though they have experienced such disruptions in the past.

The tendency to use singular information over distributional information is increased by the perceived uniqueness of the task at hand. If people have difficulty recognizing the referent class, it is less likely memories from this class will be called upon during prediction (Kahneman & Tversky, 1979, 1982). Thus, it was proposed that the best way to improve prediction is to integrate the use of distributional information with singular information in prediction.

Kahneman and Lovallo (1993) later updated the planning fallacy, discussing singular and distributional information in terms of taking an inside and outside view of a problem. The inside view is based on knowledge specific to the task, whereas the outside view is the average of how long similar tasks have taken in the past. Previously, it was proposed that prediction would be best if a mixture of singular (inside view) and distributional (outside view) information is used. In contrast, Kahneman and Lovallo stated that it would be best to use solely the outside view when planning because the inside view is susceptible to biases such as an overly optimistic outlook.

Buehler et al. (1994, 2002; Buehler & Griffin, 2003) performed the first empirical tests of the planning fallacy and further refined the theory. They found that there is a general tendency to underestimate how long a task will take in the future, even though participants were aware that they had finished similar tasks later than planned in the past. Specifically, they had participants predict when they would complete tasks such as a school assignment (Buehler et al., 1994) and compared this with actual completion time and their memory of when they finished similar tasks in the past. In one experiment, participants predicted that they would finish a computer assignment approximately 4.5 days before the deadline, even though they reported that they usually finish similar tasks about 1 day before the deadline. The tasks used in this and other experiments involved a deadline, and the participants either predicted what day the task would be finished or how long before the deadline the task would be finished. Participants finished the task closer to the deadline than they had planned, even though they were aware that a majority of their previous tasks were finished very close to deadline.

In the Buehler, Griffin, and Ross studies (Buehler et al., 1994, 2002), the distributional information that was being ignored is memory of when similar tasks were finished, usually in comparison with a deadline. Memory of past duration can be broken into two parts: (a) memory for how long it took to perform the task and (b) memory for when the task was completed. For these experiments, it is the second of these that is treated as neglected distributional information. Buehler and Griffin (2003) suggest that people are most likely to be overly optimistic about the prediction of the completion date and not the duration of the task. Further, it was put forth that simply forming a singular scenario by itself does not ensure underestimation. Buehler et al. (2002) emphasized the importance of optimism in causing underestimation. It is the belief in an overly optimistic future that causes systematic bias in scenario formation.

Attempts to Improve Prediction Accuracy

The majority of studies that have examined underestimation of future duration have attempted to correct the estimation process. To this end, participants have listed possible surprises, broken the task into individual components, made predictions about other people, formed alternative scenarios of task completion, recounted past completion times, and viewed tasks in term of aggregate frequencies. Here we review the attempts at improving prediction and look at how these different attempts may be similar in terms of both underlying theory and overall success. The studies are summarized in Table 2 and are evaluated in terms of their effectiveness at improving prediction.

Accuracy in prediction can be measured in two different manners: at the level of group means and at the level of overall variability in prediction. When accuracy is examined at the level of group means, average estimated duration is compared with average actual duration. As prediction improves, estimated duration approaches actual duration. This can be expressed in terms of percentage error. As accuracy at the group level increases, percentage of error decreases. This measure takes into account both size and direction of bias. In contrast, accuracy at the level of overall variability is concerned only with overall amount of error regardless of direction. This is often measured by examination of average absolute value of the estimated duration minus the actual duration (absolute error). Thus, if each individual's prediction is more accurate, there should be less overall error. When one considers the efficacy of an intervention, both types of accuracy—group means and overall variability—should be examined. It is possible, for instance, that an intervention could cause an improvement at the group, but not the individual, level. Some participants may shift from an error of underestimation to an equally large error of overestimation. This could cause a reduction in error at the level of group means but not a reduction in variability of prediction. For an intervention to be adopted, it is likely that an individual would have to see improvement at the level of the single case. If previous prediction was a systematic underestimation of actual duration, this may be seen as preferable to prediction via a new method in which amount of bias is still the same, but prediction moves randomly between underestimation and overestimation. Therefore, in Table 2, we indicate whether the interventions were successful both in terms of group means, with a decrease in underestimation, and in terms of overall variability, with an increase in accuracy. For the decrease in underestimation, this is expressed in terms of percentage error, with the first value indicating the percentage error for the control condition and the second value indicating percentage error for the experimental condition. Increase in accuracy is expressed in terms of average absolute error, again presented first for the control condition and second for the experimental condition. For two of the studies, Byram (1997) and Hinds (1999), absolute error values were not available either in the original study or from the authors, and, therefore, changes in overall variability for these studies are measured with the standard deviations for the predicted duration. If there was an increase in accuracy, it would be expected that there would be a decrease in variability of estimation. Although this does not give as clean a measure of variability of estimation as absolute error, because it does not take into account variability in actual duration, it does give an indication as to whether there were gross changes in variability. Also, for two other studies, Griffin and Buehler (1999) and Newby-Clark et al. (2000), data were analyzed in terms of either the number of days before deadline finished or the percentage of tasks finished by the predicted time, and, therefore, analysis could not be performed in terms of percentage error or absolute error. For these two studies, data are analyzed qualitatively.

Listing Surprises

One possible cause of the tendency to underestimate is participants ignoring the fact that completion of the task could be interrupted by problems or surprises, even though problems and surprises have been encountered in the past (Kahneman & Tversky, 1979, 1982). If participants are made aware of possible surprises before predicting task duration, then the tendency to underestimate may be lessened.

Byram (1997) had some participants list possible surprises that might arise while one builds a computer stand. There was no difference between the estimations of participants who listed surprises and those who did not, with both groups underestimating the duration. In another experiment, Hinds (1999) gave some participants a list of problems that could arise while one builds a Lego toy. Participants then predicted how long it would take for the average person to build the toy. Again, as in the first experiment, awareness of possible problems or surprises did not affect prediction or increase accuracy, with participants exhibiting an overall tendency toward underestimation.

Breaking Down the Task

A second possible cause of underestimation is that when forming a scenario of how a task will be completed, participants might forget or omit certain parts of the task. They might only plan for the main portion of the task and not some of the smaller steps. For instance, in predicting how long it will take to paint a room, the amount of time needed to move furniture and set drop cloths may not be figured into the prediction.

Byram (1997) tested the effect of breaking the task down into components for participants building a computer stand. Participants made individual estimations for three parts of a computer

Table 2
Attempts to Improve Prediction Accuracy

Method used	Study	Task	Method	Decrease in underestimation[a]	Increase in accuracy[a]
Listing surprises	Byram (1997)	Build a computer stand	Came up with possible surprises	−15% vs −21%	47 min vs 42 min (*SD*)
	Hinds (1999)	Predict time on a Lego toy task for average novice	Given list of possible surprises	−21% vs −5%	4 min vs 6 min (*SD*)
		Predict time on cellular phone task for average novice	Given list of possible surprises	−41% vs −31%	12 min vs 13 min (*SD*)
Breaking down the task	Byram (1997)	Build a computer stand	Broke task into three components	−15% vs −15%	49 min vs 40 min (*SD*)
	Connolly & Dean (1997)	Complete computer programming assignment	Broke task into eight components	−19% vs −25%	6.0 hr vs 6.4 hr
Predictions by observers versus actors	Buehler, Griffin, & Ross (1994)	Complete a computer assignment	Predicted for actor from previous study	**−19% vs +28%**	1.8 days vs 2.6 days
	Byram (1997)	Build a computer stand	Made prediction for average other	−15% vs +6%	67 min vs 59 min (*SD*)
	Newby-Clark; Ross, Buehler, Koehler, & Griffin (2000)	Complete tax returns	Predicted for actor from previous study	No improvement	
Use of multiple or alternate scenarios	Byram (1997)	Build a computer stand	Gave optimistic, pessimistic, and best guess predictions	−15% vs −15%	40 min vs 49 min (*SD*)
	Connolly & Dean (1997)	Complete computer programming assignment	Gave hypothetical scenarios aimed at improving range of estimates	**−23% vs +2%**	6 hr vs 4 hr
	Newby-Clark et al. (2000)	Complete academic assignments and tax forms	Created multiple scenarios that varied in level of optimism/pessimism, number, order, and plausibility.	No improvement	
Individual probabilities versus aggregate frequencies	Griffin & Buehler (1999)	Complete academic and nonacademic tasks	Gave individual probabilities for a number of tasks or aggregate frequencies of probability of completion by predicted date	No improvement	
Remembering the past	Buehler et al. (1994)	Complete computer assignment	Remembered how close to deadline similar projects have been finished	**−19% vs 0%**	1.8 days vs 1.9 days
	Hinds (1999)	Predict time on cellular phone task for average novice	Remembered how long it took them when they were a novice	−49% vs −44%	7 min vs 8 min (*SD*)

Note. Significant differences in boldface type.
[a] The first value indicates percentage error for the control condition, the second indicates percentage error for the experimental condition.

stand—the computer table, the keyboard tray, and the monitor stand—before making an overall estimation. There was no improvement in prediction that was a result of participants making initial estimates for the subcomponents when compared with their making only one overall estimation.

Connolly and Dean (1997) had a portion of participants estimate duration for eight subtasks of a computer programming assignment before estimating the duration of the whole task. All participants underestimated task duration, with no difference between participants who predicted subtask durations before making the whole task prediction and participants who predicted duration for the whole task first. Participants were more accurate in their predictions of the subtasks than they were for the task as a whole; they tended to underestimate subtask duration by approximately 6% compared with 23% when predicting the whole task. However, because the subtasks were much shorter than the overall task, less error might be expected because, as discussed earlier, the amount and direction of bias both appear to be affected by duration of the task.

Predictions by Observers Versus Actors

The planning fallacy suggests that prediction of duration may be better for observers than for actors. Kahneman and Lovallo (1993) held that when predicting future duration, people are likely to take an inside view during prediction and neglect the outside view. The inside view focuses on the individual task by forming a single scenario of how it will be completed, whereas the outside view focuses on the completion time of similar tasks performed in the past. It has been suggested that an individual's ego involvement in prediction may cause them to incorrectly take an inside view over an outside view (Buehler et al., 1994, 2002). An observer should not have the same ego involvement and should be more likely to take an outside view therefore decreasing the likelihood of underestimation. An observer is unlikely to form a detailed scenario of how another person will perform a task and is more likely to rely on information about how long it normally takes people to complete the task.

The results for existing studies' examination of possible differences in estimation for actors and observers are mixed. Two studies examining actors and observers, Buehler et al. (1994) and Newby-Clark et al. (2000), found differences between the two in estimation, whereas another two, Byram (1997) and Hinds (1999), found no differences.

One of the studies that found differences between actors and observers in prediction, Buehler et al. (1994, Study 5), had observers read material written by participants who had participated in an earlier study (i.e., the actors; Study 4). Participants in the first study were asked to predict how long it would take them to complete a computer assignment. During the prediction process, participants were asked to write their thoughts on how they would complete the task and how far ahead of deadline they usually finish similar projects. Observers in the second study were given the same instructions that the actors had read as well as a portion of the material written by the actor. They received either the scenario of how the actor would complete the task, the actor's recollections of completion times for similar projects performed in the past, or both. Observers then estimated how long they thought it would take the actor to complete the task. Observers tended to overestimate how long it would take the actor to complete the task regardless of what type of information they were given. This was in contrast to the actors who underestimated the completion times of the task. Although the observers were less likely to underestimate task duration, they were no more accurate, making similarly sized errors, but in the other direction. The reason for their tendency to overestimate is not clear. The planning fallacy holds that underestimation is most likely when prediction is based upon a scenario and memory of past completion times is neglected. However, there was no difference in prediction for observers who read the actors' scenarios (singular information) and those who read the actor's memory of past completion times (distributional information) before making their estimation, with both groups overestimating.

Newby-Clark et al. (2000, Study 5) also found a difference between actors and observers in prediction of future duration using a similar procedure to the previous study. Participants in an earlier study (Study 4) wrote down different scenarios that varied in how optimistic and how plausible they were. The scenarios dealt with when the actors would finish their tax return. Participants in the initial study underestimated how long it would take them to complete their taxes, with participants who wrote a plausible optimistic scenario underestimating the most. However, there was no overall effect of forming pessimistic scenarios. The experimenters were interested in whether observers would be more likely than actors to use the pessimistic scenarios during prediction. In a second study, observers read both the directions the actors were given and the scenarios they wrote. Observers who read the optimistic scenarios greatly underestimated the actor's completion time, whereas those who read the pessimistic scenarios overestimated the actor's completion time. This effect was moderated somewhat by scenario plausibility, with greater bias in prediction, both optimistic and pessimistic, for plausible scenarios. Although observers were more likely than actors to be affected by having read the various scenarios, both optimistic and pessimistic, they were also markedly less accurate than the actors.

In contrast to the previous two studies, Byram (1997) found no difference between actors and observers in prediction time. Participants were required to estimate either how long it would take them to build a computer stand or how long it would take for the average person to build the stand. There was no significant difference between those predicting for the average person and those estimating for themselves, with both groups underestimating actual task duration.

A similar tendency to underestimate how long it will take others to complete a task was found by Hinds (1999). In two experiments, participants estimated how long it would take others who were novices in either a cell phone task (Study 1) or a Lego toy task (Study 2) to complete the task. There was an overall tendency to underestimate how long others would take, with underestimation greatest by experts at the task. For the Lego toy task, participants were asked to estimate how long it took them to complete the task when they were new to it. Similar to when they were predicting for others, participants underestimated how long it took them to complete the task, with underestimation being greatest for participants with more experience with the task. However, although this study indicates that there was a tendency to underestimate others' average duration that is similar to the participants' memories for how long it took them to perform the task in the past, there was no direct comparison between the predictions of actors and observers.

In summary, the results for these four studies are mixed. For two of the studies, observers were less likely, at least in some of the conditions, to underestimate future task duration than were actors. In the second two studies, observers, like actors, tended to underestimate how long it would take others to perform a task. However, in none of the studies were observers more accurate than actors. Although at times the tendency to underestimate was eliminated, it was replaced with an equal if not larger bias in the other direction. The differences between studies may be due to differences in methodology. The first two studies had observers make predictions for others on the basis of written material from actors in other studies, whereas the second two had observers predict for an average other person. It may be that when predicting for the average other, people simply based predictions on themselves, and, therefore, a similar bias emerged. In the other studies, predictions were based on material written by an actual person, and the material written by the actor may or may not have reflected the actor's true beliefs. If it did not, then this could account for why the written material affected the observer's prediction to a greater degree than it did the actor's prediction. If the actors did not fully believe what they had written, they would simply ignore this information during prediction. Observers, on the other hand, only had the written material to help them in their prediction. Overall, it is unclear what effect being an observer instead of an actor has on making a prediction about duration. Instead of using a hypothetical other or materials written by a previous actor to study actor–observer differences, a greater understanding of any possible differences may come from using observers making predictions on task duration for a live actor and comparing these predictions with those made by the actor.

Use of Multiple or Alternate Scenarios

In an attempt to stop underestimation, studies have also examined the effect of imagining multiple scenarios regarding how the task might be completed before predicting duration of the task (Byram, 1997; Newby-Clark et al., 2000). Thinking of multiple scenarios may give a more realistic view of all the ways a task may be completed, including possible problems that might arise and ways that progress might be impeded, and could thereby eliminate underestimation. In turn, this manipulation may also force participants to recall memories of past task completion to help form the different scenarios. The hope is that forming many different scenarios would eliminate the optimism that is thought to dominate when only a single scenario is used (Buehler et al., 2002; Newby-Clark et al., 2000).

Byram (1997) had participants create multiple scenarios by asking them to come up with optimistic, best guess, and pessimistic predictions for how long it would take to build a computer stand. When compared with the results of participants who made only a best-guess prediction, there was no improvement that was a result of participants making multiple predictions, with all participants underestimating duration. In a follow-up study, the order of the predictions was varied, with half making the pessimistic prediction first and half making the optimistic prediction first. This also had no effect.

Newby-Clark et al. (2000) made the use of scenarios more explicit by having participants write scenarios instead of just imagining them. Participants recorded different scenarios predicting how long it would take to finish a school assignment or to complete their taxes. The tasks varied in their level of optimism or pessimism of the scenario, number of scenarios formed, order of scenarios and plausibility of the scenario. For the most part, they found little effect of the scenarios on prediction times, with participants consistently underestimating how long it would take to finish.

Connolly and Dean (1997) used the formation of multiple scenarios in a different way and toward a different purpose. In their initial study, in addition to finding an overall tendency to underestimate task duration, Connolly and Dean found that predictions were overly tight. They had participants make estimation distributions for a project by predicting duration of completion that should happen 1% of the time, 25% of the time, and onward, up to 99% of the time. They found that the ranges of estimates given were much too small when compared with actual range of completion times. In a second experiment, they had participants imagine hypothetical scenarios to try to increase the range of their predictions. For example, they had participants explain why a car trip could have taken much longer than was originally thought possible. Participants were asked to create a number of such scenarios for a task going extremely well and extremely poorly. Unlike the previous experiments, scenarios formed here were not for the task at hand but for a hypothetical other task and were aimed at increasing variability in predictions. In comparison with participants in Connolly and Dean's first study, participants forming these scenarios increased their range of prediction and were also less likely to underestimate the overall task duration. Although the intervention did reduce the tendency to underestimate, there was not a significant reduction in amount of error. Also, these results must be interpreted cautiously because the comparison is being made across different experiments. In the first experiment, participants were all students in an advanced computer programming class and were making predictions for a class project. In the second, some participants were in a lower level programming class. As we discuss in greater detail later, it appears that level of experience with a task can affect prediction, such that the amount of underestimation is greatest for participants with a higher level of experience with the task (Boltz et al., 1998; Hinds, 1999). This difference between groups could have affected the overall outcome.

Individual Probabilities Versus Aggregate Frequencies

Griffin and Buehler (1999) examined whether there was a difference between participants' confidence ratings of when they would finish a project using individual probabilities and aggregate frequencies. It has been proposed that certain biases may be reduced if the problem is thought of in terms of frequency representations instead of in terms of probabilities (Gigerenzer, 1998). Participants were asked to list 10 academic and personal tasks they were planning to finish in the next week and the day and time that they thought they would complete each. They then gave the individual probability that each task would be completed by the time indicated. They were also asked how many of the 10 projects would be finished by the dates indicated. The order of the probability and frequency questions was counterbalanced. Overall, the participants greatly underestimated the number of projects they would have finished by the dates indicated. There was no difference between the amount of underestimation for the probability and frequency judgments when the two were compared. Participants greatly underestimated the number of tasks they would have finished, and the use of frequency or probability judgments had little overall effect.

Remembering the Past

A final way to have participants take into account memory of past task duration when predicting future duration is to simply ask them to remember their own history of how long it normally takes them to finish a project. Buehler et al. (1994) had participants link predictions of future duration with memories of past duration. Participants were given a computer assignment and a deadline for completing it. There were three groups: (a) participants who only predicted when they would finish, (b) participants who were asked to remember past completion times of similar tasks and keep them in mind while they predicted when they would finish, and (c) participants who were asked to remember past completion times of similar tasks and to take these into account when predicting when they would finish by forming a scenario in which their current project would finish roughly as close to the deadline as their past projects. On average, there was no difference between the first two groups, with both underestimating how long the task would take. There was a significant decrease in underestimation for the group that made an explicit link between past experience and their prediction. However, there was no change in absolute error (average absolute value of the difference between predicted duration and actual duration) that was a result of the manipulation. There was a shift in the correct direction at the mean level but not an increase in individual accuracy.

Hinds (1999) used a similar intervention to try to improve experts' predictions of how long it would take a novice to perform a task. Participants were asked to remember how long it took them to complete a cellular phone task when they were new to it and use this as a basis for prediction. There was no difference between these participants and others who were not asked to remember the past, with both groups underestimating how long the task would take.

Summary

Overall, there has been little success in improving prediction. The few studies that did improve prediction at the level of group means did not improve prediction at the level of overall variability: There was a shift in means in the correct direction but not an overall reduction in error. The majority of interventions were aimed at trying to have participants better use memory. It is possible that these studies are focusing on the wrong method of correcting underestimation. In the following sections we propose an alternative method for correcting prediction: correcting memory of duration before prediction. First, however, we examine a separate class of debiasing methods that are concerned with changing behavior subsequent to prediction.

Changing Behavior After Prediction

The studies reviewed in this section have been concerned with methods of correcting prediction, but there are other possible ways to lessen underestimation of future duration. For example, a possible method for correcting underestimation is to change behavior after prediction is made rather than altering the prediction. Both Koole and Van't Spijker (2000) and Taylor et al. (1998) have had some success with changing behavior by having participants imagine themselves completing the task. Koole and Van't Spijker had participants form "implementation intentions" (Gollwitzer, 1999; Gollwitzer & Brandstatter, 1997) by picking a time and place where they would complete a writing assignment and visualizing themselves in this context. Taylor et al. (1998) had participants envision themselves completing steps necessary to finish a project of their own selection. Both interventions had some success at limiting underestimation, indicating that a possible way to lessen underestimation is to focus on the behavior subsequent to prediction. Bringing behavior in line with prediction created a reduction in bias. This method is in contrast to the previous attempts at improving predictions, which were only concerned with improving the predictive process and were not concerned with subsequent behavior. However, this does not mean that all problems in underestimation of future duration are due to behavior after prediction. For instance, it is unlikely that these techniques would be successful in laboratory studies in which the possibility of interruptions happening or becoming distracted by another task is low. Also, it is quite possible that although these interventions had some effect on participants finishing their projects closer to their proposed finishing time, participants still may have underestimated how long it would take them to complete the task. The visualization techniques might have made the participants more motivated to persist with the task even when it was taking longer than they had originally planned.

There also may be a downside to interventions such as these. In a similar manner to the experiments by Koole and Van't Spijker (2000) and Taylor et al. (1998), Buehler and Griffin (2003) had a portion of their participants think about the task at hand and envision when, where, and how they would complete the task. Here the intervention caused participants to predict an even earlier completion date when compared with participants who did not form imagery, but the intervention produced no difference between groups for when they actually finished the task.

Memory Bias

The underlying theme common to a number of the previous attempts at correcting predictions of future duration is that the prediction process is flawed because people incorrectly use their memories of similar past tasks. In contrast, but not exclusively, we propose that people do use memories of past tasks when predicting future task duration, but because of a memory bias, their predictions are incorrect. Error comes not from ignoring accurate past memories but from using inaccurate ones. Predictions based upon biased memories will also be biased.

Generally, memories of past duration will not be based on the actual past duration but on an estimation of past duration. Given that people rarely check the precise starting and ending times for a particular task, they must generally estimate how long past tasks have taken. If people remember a task as taking less time than it actually did, then it follows that predictions about future task duration based upon such memories will lead to underestimation.

Our review of studies in which future duration is estimated revealed an overall tendency toward underestimation. However, there do seem to be instances, such as with short or novel tasks, in which overestimation is likely. Memory bias provides not only a possible explanation of why there is a tendency to underestimate but also of when it is likely to happen and of when, instead, overestimation is likely. Results from experiments examining retrospective estimation of duration can identify variables that are likely to influence memory of duration. We can then use this knowledge to better understand the likely size and valence of bias in prediction.

It might seem that memory bias is inconsistent with the fact that people are often aware that tasks have taken longer than planned in the past, yet they still continue to underestimate how long those same tasks will take in the future. If people are aware of mistakes, why do they not then correct memory to reflect this knowledge? To fix biased memories of duration, it is first necessary for one to identify them as the cause of the problem. If people think that the reason they underestimate future duration is because of a tendency to be overly optimistic and incorrectly utilize memory, then they will not see memory as the culprit. People may believe that memories of past task duration are accurate and that errors in prediction occurred because these memories were not correctly utilized. This is especially likely on a longer task that is completed over a number of different sessions in which people may blame their failure to finish on time on intervening events or interruptions. Further, when asked to estimate how long it took to complete the task, people may still underestimate the actual duration even though they are aware that the task took longer than planned. People may believe their finishing later than planned was due to not taking other events and problems into account rather than to having an incorrect memory of how long that task has taken. To state this another way, memories of task duration may be incorrect while memories of task completion time may be correct. If it is memory of task duration that is called upon for prediction, and not memory for completion time, this would lead to error. It would be informative to examine whether there is a difference in the accuracy for memory of task duration and memory of task completion date. This could be performed by having participants perform a task in which both time spent on task and time of completion are tracked and then, after a delay, having participants estimate both of these values.

Memory bias also supplies a possible method of correcting prediction: correcting memories of past task duration. If prediction is biased because of biased memory, then one needs to correct memory. This could be done by keeping track of time spent on a task, which would be especially important for tasks that are completed over multiple sessions. If this is done repeatedly, then averages and variability could be computed for the task and used during prediction.

Although we are proposing that memory bias can account for much of the error in prediction, prediction is likely multiply determined. As with other psychological influences of behavior, it is unlikely that one factor can account for all variability (Stanovich, 2001). For example, at times people may be overly optimistic or narrow in our focus on a task, and these factors may act individually or in concert with each other and memory bias to cause an overall tendency to underestimate.

Predictions

In the remainder of this article, we examine four questions about time estimation in which memory bias makes specific predictions. The predictions made by memory bias are contrasted with a general model on the basis of what would be expected if error was due to memory being incorrectly used (see Table 3). In this section we give an overview of the four questions. In the following four sections, we review research relating to these predictions and find that in each case, the available evidence lends support to the memory bias account.

1. Do People Disregard Memories of Past Duration?

The memory bias explanation of inaccurate prediction suggests that people do use memories of past duration when making predictions about duration of future tasks. However, there is a tendency for memory of past task duration to be biased. Prediction of future duration is incorrect because the relevant memories are incorrect.

In contrast, if memory is incorrectly used, then the memories of the past are not used when making predictions. Because of optimism, people do not use all available memories when making a prediction. This account suggests, although it does not require, that memory is correct. If error occurs because memory is disregarded, then one possible way to correct prediction is to make memory more salient (Buehler et al., 1994, 2002; Kahneman & Lovallo, 1993; Kahneman & Tversky, 1979, 1982). This will only be an

Table 3
Divergent Predictions of Underestimation as Due to Memory Bias or Memory Not Used

Questions about estimation	Memory bias	Memory not utilized
1. Do we disregard memories of past duration?	Memory of past is incorrect, leading to bias in prediction.	Memory of past is correct but is not consulted during prediction.
2. Is there a difference in prediction when tasks are novel?	Well-learned tasks are more likely to be underestimated.	Novel tasks are more likely to be underestimated.
3. Do variables that affect memory of duration affect prediction of duration?	Variables that affect memory should have a similar affect on prediction.	Variables that affect memory should not necessarily affect prediction.
4. What methods will prevent underestimation?	Correcting memory of past duration.	Increasing salience of memory of past duration.

effective intervention if memory is correct. If memory is biased, increasing saliency will not remove bias in prediction.

2. Is There a Difference in Prediction When Tasks Are Novel?

Memory bias predicts that there should be a difference in the prediction process when a task is novel compared with when it is well learned. If underestimation of future duration is based upon memories of past duration, then the tendency to underestimate is likely to happen when there are memories upon which to base prediction. Although it is clear that the future duration of well-learned tasks should be underestimated, it is hard to predict what should happen when the task is novel. It might be that novel tasks are overestimated or that there is greater variability in prediction.

If the problem is that memory is not used, then the tendency for underestimation should be greatest when there are no previous experiences with the task. Kahneman and Tversky (1979) suggested, "The tendency to neglect distributional information and rely mainly on singular information is enhanced by any factor that increases the perceived uniqueness of the problem" (p. 316). If a task is seen as unique, then memory is unlikely to be used, and prediction will be based almost entirely on an overly optimistic scenario. One way to increase the perceived uniqueness is to increase the actual uniqueness. It would then be expected for underestimation to be greatest for a novel task. If the problem is that people create overly optimistic scenarios when making predictions, then the lack of any memory to ground our predictions in reality will create even greater reliance on these optimistic scenarios.

3. Do Variables That Affect Memory of Duration Affect Predictions of Duration?

The memory bias account suggests that variables affecting memories of past duration should similarly affect predictions of future duration. If something, such as the way a question is framed, causes a participant to have a different memory of duration, then that participant should give a corresponding prediction of future duration. The variable causes a change in memory of duration, which, in turn, causes a change in prediction.

If memory is not correctly used, then variables affecting memory should have little effect on prediction of future duration. If people do not properly consult memory for prediction, then variables causing differences in memories of duration need not cause corresponding changes in prediction.

4. What Methods Will Prevent Underestimation?

The memory bias account predicts that supplying feedback about true past duration should improve prediction. If errors in prediction are based on incorrect memories, then correcting memory should eliminate underestimation. Participants basing predictions upon estimations of past duration should underestimate how long the task will take, whereas participants basing predictions on feedback of the true duration of the event should not. Increasing the salience of memory for past task duration should not affect prediction. Because memory is already being used in making predictions, increasing awareness should not affect prediction of duration.

If the problem is that people ignore the past, or that memory is not correctly used, then making past experiences salient should eliminate underestimation. Giving accurate feedback on event duration should not necessarily improve estimation of future duration, because the problem lies not in the memory but in that people ignore it.

1. Do People Disregard Memories of Past Duration?

Memory bias is based on the assumption that people use memories of duration when making predictions of future duration and that biases in these memories cause biases in prediction. It is because the memories are incorrect that prediction of future duration is incorrect. In contrast, if underestimation is due to ignoring or not correctly utilizing memory, then people likely have correct memories at our disposal, but they fail to use them.

Evidence used to support the notion that people do not take the past into account when estimating future duration comes from experiments that use think-out-loud procedures during the prediction process (Buehler et al., 1994, 1997). When supplying reasons for their prediction of when they will finish, the majority of participants mention only future plans and rarely mention the past. Specifically, they frequently fail to mention the duration of similar tasks performed in the past, which has been taken to suggest that participants are using only singular, not distributional, information.

However, there is reason to question the results of the think-out-loud procedure performed in these experiments. First, as can be seen from experiments examining attitude stability, it not clear that people have a clear understanding of why they make certain decisions or can accurately describe their decision-making process (Wilson & Hodges, 1992). Second, it may be that participants treat their memories for the past completion times as a given that does not require mentioning. The process of remembering past task duration when making a prediction may be so basic that the participants do not think to mention this when describing how they formulated their prediction. Participants rarely mentioned deadlines for projects when making their predictions, although their completion times were highly correlated with their deadlines (Buehler et al., 1994). Similarly, when participants were given feedback on duration of practice trials for a task before predicting how long it would take to perform the task again, only a little over half mentioned the past duration when making their prediction. However it is likely that they used the information, as the correlation between participants' prediction times and previous practice times was .94 (Buehler et al., 1997). Although many failed to mention it in the think-out-loud procedure, it appears that prediction was influenced by their previous times. This indicates that prediction times may be grounded in memory of the past, even if participants fail to mention it.

The proposition that people do use memory in prediction is further supported by the fact that although participants are underestimating duration, their predictions of future duration are not indiscriminately optimistic but are instead based in reality (Armor & Taylor, 1998, 2002). There is a strong correlation across participants between prediction times and completion times for a given task (Buehler et al., 1994, 1997). Participants seem to have a good idea of how long a given task will take, although there is a systematic underestimation.

Additional support for memory bias comes from studies on memory for past duration. For the memory bias account to be plausible, there should be a tendency for time to be underestimated retrospectively. Retrospective estimation has received much greater attention and has a longer history as a topic of research than does future estimation, and there have been several reviews of this topic. Consistent with memory bias, these reviews of studies of retrospective estimation of duration have found there is a general tendency to underestimate past duration for longer events (Block & Zakay, 1997; Fraisse, 1963; Poynter, 1989; Wallace & Rabin, 1960). There is some reason for caution in relating results of studies of retrospective estimation to the real world. Most studies have used durations of 1 min or less (Fraisse, 1984), and the tasks used often involved fairly novel and arbitrary stimuli, such as listening to regularly and irregularly spaced tones (Ornstein, 1969), staring at geometric shapes (Predebon, 1996), and looking at colored lights (Brown, Stubbs & West, 1992). However, this same tendency to underestimate past duration has also been found with longer, real-world events. For example, Burt and Kemp (1991) found systematic underestimation when participants estimated the duration of public events such as the war over the Falkland Islands and the U.S. Embassy hostage situation in Iran.

Circadian rhythm studies in which participants spent a portion of time in an isolation unit show a similar tendency for underestimation of duration (see Campbell, 1990, for review). These studies have found there is a tendency for our internal clock to run slow, resulting in a sleep–awake cycle that lasts approximately 25 hr. Also, when asked to estimate time in passing, usually for a duration of about an hour, participants underestimated the amount of time that has passed. For six studies that had participants estimate passing time, underestimation of duration ranged between approximately 2% and 47% with a median of 12%. This can be compared with the results of the studies in which underestimation was found for prediction of future task duration. In those studies, underestimation of duration ranged between approximately 1% and 46% with a median of 15%. This indicates that not only is the bias toward underestimation for both perceived and predicted duration similar in valence, but it is also similar in size.

Evidence for the tendency to underestimate past duration also comes from studies examining the phenomenon of "telescoping" (Betz & Skowronski, 1997; Huttenlocher, Hedges, & Bradburn, 1990; Loftus & Marburger, 1983; Rubin & Baddeley, 1989; Thompson, Skowronski, & Lee, 1988). In these studies, participants estimated when, in the past, certain personal events happened. There is a marked tendency to underestimate how long ago the event happened. This is especially true for events that happened more than 8 weeks earlier (Thompson et al., 1988). Although these studies do not examine estimations of event duration, they do suggest a tendency toward underestimation of prior duration. People remember events, or in this case duration since these events happened, as being shorter than they actually are. However, as with memories of past task duration and memories of when a task was completed, the cognitive processes underlying the telescoping phenomenon (i.e., when an event took place) might be quite different than those used in estimating event duration.

Although more research needs to be conducted in this area, it is evident that there is a tendency to underestimate past duration. It is possible that the estimations of past and future duration are not related and that the tendency for underestimation in both is merely coincidental. However, it also possible that the tendency to underestimate duration retrospectively explains the tendency to underestimate duration prospectively. Future research needs to examine whether bias in memory for a particular task is similar in size and valence to bias in predicted duration for the same task.

2. Novel Versus Well-Learned Tasks

If, as suggested by memory bias, underestimation of future duration is based upon memories of past duration, then the tendency to underestimate is most likely to be present when there are memories upon which to base prediction. Although it is clear that the future duration of well-learned tasks should be underestimated, it is harder to predict what should happen when the task is novel. It is likely that there will be greater instability in prediction of duration for novel tasks, leading to greater variability in prediction. In contrast, if underestimation is due to incorrectly used memory, then it might be expected that underestimation would be even greater if the task is novel. If the problem in prediction is that people do not sufficiently take the past into account and allow themselves to be overly optimistic, this tendency should be greatest when there are no memories of past duration on which to ground prediction.

Two studies examined the effect of level of familiarity with a task on estimation of future duration (Boltz et al., 1998; Hinds, 1999). In one study, pianists unfamiliar with a piece of music overestimated by 48% how long it would take to play the piece, whereas pianists very familiar with a piece of music underestimated by 19% how long it would take to play (Boltz et al., 1998). In the second study, participants predicted how long it would take a novice either to complete a cell-phone task or to build a Lego toy. In this study, underestimation was greatest for participants with the highest level of expertise in these tasks: For the cell phone task, novices underestimated how long it would take by 50%, whereas experts underestimated by 59%, and for the Lego toy task, novices overestimated by 3%, whereas experts underestimated by 32% (Hinds, 1999). Thus, at least for some of the tasks, there was a tendency toward overestimation for the future duration of novel or newly learned tasks. In both studies, with increased familiarity with a task, there was a greater tendency to underestimate how long it would take.

We find it interesting that a similar pattern emerges with task familiarity on retrospective estimates of duration. Boltz et al. (1998) manipulated the number of times participants either used a statistical software package or built an erector-set car. Participants who only performed the task once (low familiarity) overestimated the duration of the task by 40% retrospectively, whereas those who performed the task three times (high familiarity) underestimated the duration by 28%. In addition, Hinds (1999) had participants retrospectively estimate how long it had taken to build a Lego car on their first practice trial. Participants highly familiar with the task, those who performed more intervening practice trials, underestimated duration of their initial attempt more than did participants low in familiarity (24% compared with 4%).

The memory bias account provides a simple explanation of why greater familiarity with a task leads to greater underestimation of future event duration: Experience with a task makes it more likely that retrospective task duration will be underestimated, which, in turn, makes it more likely that future task duration will be underestimated.

In sum, it appears that the tendency to underestimate future duration is tied to memory of past duration; underestimation is most likely to occur when there is a sufficient memory of the past available. Furthermore, level of familiarity with a task affects memory of duration and prediction of future duration in the same way. As memory changes because of increased experience, so does prediction.

3. Variables Affecting Memory

Past research has found that certain variables, such as duration of the task (Yarmey, 2000) and motivation to finish quickly (Meade, 1959, 1960, 1963), can affect memory of duration in terms of both size and direction of bias. In this section, we examine how these two variables affect both memory of past duration and prediction of future duration. If, as proposed by memory bias, memory and prediction are linked, then variables that affect memory should have a similar effect on prediction. If something, such as the way a question is framed, causes a participant to have a different memory of duration, then the way the question is framed should cause a corresponding change in prediction of future duration. Any variable causing a change in memory of duration should cause a change in prediction. On the other hand, if people disregard or incorrectly use memories of past duration, then there is no reason to think that memory of duration and prediction of duration should be affected in the same way. If people do not consult memory for prediction, then variables causing differences in memories of duration need not create corresponding changes in prediction.

Duration of the Task

It has long been noted that task duration can affect the accuracy of memory of duration. One of the earliest descriptions of this phenomena, Vierordt's Law (Vierordt, 1868), states that in retrospect, tasks of short duration tend to be overestimated, whereas tasks of long duration tend to be underestimated. More recent reviews of retrospective time estimation studies have come to the same conclusion (Fraisse, 1963; Poynter, 1989; Wallace & Rabin, 1960). In this section, we try to determine whether, as predicted by memory bias, task duration affects future estimation of duration—both overestimation and underestimation—in the same manner it affects estimation of past duration.

Yarmey (2000) examined retrospective estimation of duration for tasks that ranged from 4 s to 80 min in a natural environment. After people were observed performing different activities, they were asked to estimate how long it had taken them to complete the task. Tasks were separated into two groups: variant events that had irregular temporal patterns, such as stirring coffee, eating at a restaurant, and socializing with a friend, and invariant events that had regular temporal patterns, such as walking a specified distance, washing one load of laundry, and riding one stop on a subway. Two results emerged from the study. First, variant events were more likely to be overestimated than invariant events. This result is in line with previous research by Boltz (1993, 1995, 1998), who found that tasks that are less coherent or predictable are more likely to be overestimated retrospectively than tasks that are more coherent or predictable. Second, in support of Vierordt's Law, participants tended to overestimate the shorter tasks and underestimate the longer ones. Figure 2 shows the signed percentage error for the invariant events. We focus on the invariant events here because they are more similar to the tasks used in the experiments examining future duration estimation. The six tasks with duration of 2.5 min or less were overestimated by between 17% and 75%, whereas the tasks longer than 13 min were more accurate, with error ranging from 10% overestimation to 12% underestimation.

The pattern of over- and underestimation of past duration can be compared with the results of the studies in which prediction of future duration is made, summarized in Figure 1. Here a very similar pattern emerged: Tasks of less than 5 min were likely to be overestimated, tasks lasting between 5 min and 12.5 min were more accurate, and tasks longer than 12.5 min were likely to be underestimated. For both past and future duration estimation, short tasks were likely to be overestimated, whereas underestimation was most likely for longer tasks. However, there are differences between the two types of estimation that is evident in the two figures; specifically, amount of overestimation and underestimation appears to be more extreme for future estimation. One possible reason for this is that the comparison is over a number of different studies that used different tasks and different methods. In addition, the data for the Yarmey study are based upon mean estimated and actual duration, whereas the data for most of the future estimation studies are based upon median estimated and actual duration. Because the distribution of estimates of duration, and to a lesser extent actual task duration, are often skewed, use of medians versus means for these studies could account for the different results. For example, one experiment (Boltz, 1998) found that for a certain task, the mean of participants' retrospective estimations overestimated the duration even though a majority of

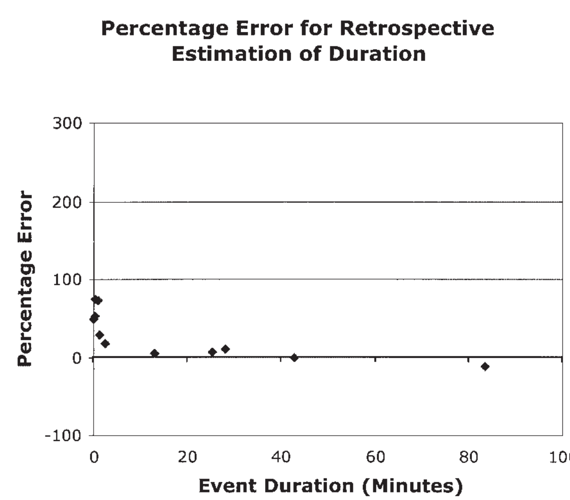

Figure 2. Signed percentage error for remembered task duration as a function of task duration as reported in Yarmey's (2000) study. The data in Figure 2 are from "Retrospective Duration Estimations for Variant and Invariant Events in Field Situations," by A. D. Yarmey, 2000, *Applied Cognitive Psychology, 14*, p. 51. Copyright 2000 Wiley-Liss, Inc., A Wiley Company. Adapted with permission.

participants underestimated the duration. A second possible reason for the differences is that although the overall patterns are similar, the underlying cognitive mechanisms are different, causing the future estimation to be more extreme. More investigation is necessary with direct comparisons made between retrospective and future estimation for the same task with the same methods. However, at least tentatively, we can state that consistent with the memory bias account, past and future duration estimations appear to be affected in the same way by duration of the task.

Although these experiments show that there is a difference between short and long tasks in estimation, it is unlikely that there is a single simple cutoff point that can be applied to all tasks. As seen previously, variables such as task novelty can have a large effect on how likely that task is to be overestimated or underestimated and would therefore affect what could be considered short or long for that task. The frame of reference may also be important, because a task that takes an hour is considered long when the frame of reference is minutes but considered short if the frame of reference is days. Early work by Vierordt (1868) and others was concerned with time estimation in terms of seconds and fractions of a second and found that intervals less than 1.4 s were likely to be overestimated, and longer duration was likely to be underestimated. The tasks discussed here, by Yarmey (2000) and others, deal with a frame of reference of minutes, with tasks less than approximately 3 min more likely to be overestimated. Finally, in an experiment in which participants estimated how long ago a certain event took place, with a frame of reference of weeks or months, Thompson et al. (1988) found that estimated durations for events less than 8 weeks prior were likely to be overestimated, and those more than 8 weeks earlier were likely to be underestimated. These studies indicate that people may have separate scales that they use when judging duration in terms of seconds, minutes or hours, or weeks or months, with even more subdivisions possible.

Motivation for Quick Completion

The desire to finish a task quickly can cause even greater underestimation of future duration. Participants given a monetary incentive to perform faster on a word game (Buehler et al., 1997) or origami task (Byram, 1997) predicted shorter completion times than participants not offered an incentive. In a similar manner, participants expecting a tax refund predicted finishing their taxes earlier than participants who had to pay additional taxes (Buehler et al., 1997). We find it interesting that the monetary incentive had little effect on the actual speed of completion for most of the tasks. The motivation caused participants to change their predictions but had little effect on their actions. It may be that motivation for quick completion causes even greater optimism and disregard of memory of completion time of similar tasks. However, it is also possible that in line with memory bias, motivation for quick completion affects memory of how long that task has taken in the past, which in turn affects prediction of how long it will take in the future.

In fact, there is evidence that motivation for quick completion does change retrospective estimations of duration. In a set of experiments, participants were told that the task they were about to perform, a wood block puzzle or a stylus maze, either measured IQ or was simply an innocuous game (Meade, 1959, 1960, 1963). After completing the task, participants who thought the game was an IQ test, and therefore had motivation to do well, estimated that the task had been shorter in duration than did participants told the task was an innocuous game. Motivation here appeared to change memories of past duration.

It has also been found that in addition to state motivation, trait motivation can affect retrospective estimation of time (Conti, 2001). Conti had participants fill out questionnaires estimating the time of day and answering questions about their current activities whenever an electronic planner sounded. Participants with high intrinsic motivation scores on the Work Preference Inventory (Amabile, Hill, Hennessey, & Tighe, 1995) were more likely to underestimate how much time had passed. They also checked the time and thought about time less often. It seemed that high intrinsic motivation made people less aware of time, which in turn caused them to underestimate how much time had passed.

Although it is not surprising that incentives may change how people view future performance, the effect of motivation for quick completion on memory is somewhat unexpected. It appears motivation for speed has the effect of shortening both past and future estimations. It is possible that they are part of the same process: Motivation for speed causes us to shorten our memory of the past, and therefore, shorten future expectations. Perhaps instead of making us ignore our past, it changes our view of the past.

This is not to say, however, that motivation for quick completion cannot at times override memory. Evidence that motivation can make participants fail to use memory comes from the second Buehler et al. (1997) experiment, in which the participants were given feedback on their practice times before they made their estimations. Here the difference between the groups because of the presence of a monetary incentive could only be due to the effect of motivation on expected duration. It does not seem likely that they would change their memory for how long the task took right after they were told the duration of their practice trials. Although this does show that motivation can override memory, it is important to note that participants would only receive money if they performed the task faster than they did during the practice trials. A prediction of no improvement over previous times would, in the end, be the same as a prediction that no money would be earned. It seems unlikely that any participant would do this even if they thought that it would be hard to go any faster, and participants did, in fact, perform the task faster than on previous trials, although not as much faster as they had predicted.

It seems fair to say that more research needs to be conducted on the relationship between past and future estimation and the motivation for speed. Although we can, at least tentatively, state that both past and future estimation generally appear to be affected by the motivation for speed in the same way, it is not clear whether the two are linked. There are, however, potential problems when level of motivation is varied. For instance, the motivation manipulation may not affect the participants' perception or memory of time but may affect the way that the participants present themselves to the experimenter (e.g., as being intelligent or industrious).

Summary

When the results of this and the previous section are taken together, it appears that both memory for task duration and estimation of future task duration are similarly affected by level of experience with the task, task duration, and motivation for quick completion. In all three cases, more experiments are needed to be able to make more direct comparisons. This could be done by taking one task, varying it along one of these dimensions, and having participants estimate the duration either before or after performing the task. Further, the three variables discussed here by no means represent an exhaustive list of all variables that may affect memory or prediction, and the same technique could be applied to a number of additional variables.

It is possible that similarities between memory and prediction found for these three variables is merely coincidence and that these results would not hold for other variables. For instance, there is an apparent difference in the effect of task segmentation on memory and prediction. It has been found that the number of changes in a task or task segmentation can affect memory for duration, such that greater segmentation leads to longer duration estimation (see Poynter, 1989, for review). A representative study by Block (1992) found that for a lexical-decision task lasting 2 min 40 s, estimated duration was longer if the type of decision was changed during the task than if it stayed the same. This would imply that breaking down a task into discrete components, instead of viewing it as a whole unit, should lengthen estimated future duration. However, this was not found in the experiments by Byram (1997) and Connolly and Dean (1997), in which participants were asked to first take into consideration the various subsections of the task before making an overall estimation of expected duration. There was no difference in overall predicted estimation for participants who first considered the subsections and for participants who did not. One possible reason for this difference is that memory for past duration and estimation of future duration is unrelated. Another possible reason for the difference is the difference in experimental design. For the retrospective studies, the tasks took place in the lab and were fairly novel with durations of approximately 4 min or less. In comparison, the Byram (1997) and Connolly and Dean (1997) studies used more real-world tasks with much longer durations, 70 min and 11 hr, respectively. As discussed earlier, task novelty and duration can have large effects on estimation. Because the retrospective and future studies are different along both of these dimensions, any comparison between the two is complicated.

The difference in methods used in these studies helps to underscore an overall difference between much of the work on retrospective and future duration estimation. Much of the work on retrospective estimation is theory driven and examines whether estimation can be better explained in terms of the number of contextual changes (Block & Reed, 1978), memory storage size (Ornstein, 1969), or attentional resources (Thomas & Weaver, 1975). Such questions lead to experiments that use tasks that tend to be fairly novel and brief to tease apart the subtle differences in the theories. In contrast, most of the studies of future task estimation are concerned with whether there is a general bias, and if there is, how to get rid of it. Because the aim is to find a solution to an everyday problem, the research is generally done with everyday tasks.

4. Methods for Preventing Underestimation

Memory bias suggests a straightforward way for correcting underestimation. It predicts that providing people with feedback of true past duration should improve their predictions. If errors in prediction are based on incorrect memories, then correcting memory should eliminate underestimation. Simply increasing awareness of memory for past task duration should not affect prediction, as memory is already being used in prediction. People basing predictions upon estimations of past duration should underestimate, whereas those basing predictions on feedback of the true duration of the event should not. By contrast, if bias is due to participants incorrectly using memory, then we would expect that increasing the salience of memories, whether they be of past task duration or for possible surprises and interruptions, would increase accuracy. As reviewed earlier, increasing saliency of memory had little overall effect in increasing accuracy of prediction. In the following section, we examine evidence for the efficacy of an alternative method—supplying feedback—to correct memory on improving prediction.

The results of two experiments indicate that correcting memory of duration might be effective in improving estimation. In an experiment concerned with the effect of motivation for quick completion and accuracy on prediction times, participants were given feedback on the duration of practice trials (Buehler et al., 1997). The presence of feedback was not varied; all participants received feedback on duration of practice trials. Participants performed an anagram-type task a total of three times, with the first two being timed practices with performance feedback given. In a 2×2 design, with motivation for speed and for accuracy varied using a monetary incentive, participants were then asked to estimate how long it would take to do the task a third time. As discussed previously, the incentive for quick completion did cause participants to underestimate task duration, but in the other three conditions (no incentive, incentive for accuracy, and incentive for both speed and accuracy), participants' predictions were not significantly different from actual duration. It appears that participants in these three conditions used the feedback in making their predictions, as indicated by a correlation of .88 between the results of their practice trials and the estimation they gave for completing the task again. These results indicate that one way to lessen the tendency to underestimate is to have accurate knowledge of past completion times, as predicted by memory bias. However the results must be interpreted with some caution for two reasons: (a) Feedback was not used as an independent variable here, so it is not known what the results would have been if it were not given, and (b) the task was fairly short in duration, 5 to 7 min, and, as we have seen, shorter tasks are less likely to be underestimated.

In a similar manner, though with a different phenomenon, Loftus and Marburger (1983) found that the effects of telescoping (underestimating how long ago an event occurred) could be lessened by having participants think of landmark events when estimating how long ago something happened. In general, participants remember autobiographical events as happening more recently than they actually did. However, if people were given a certain concrete event to use as an anchor, such as the eruption of Mount St. Helens or New Year's Day, their tendency to underestimate how long ago the event happened was lessened. Being provided with landmark events enabled participants to use the anchor point to correct their memory of the duration and increase accuracy of their estimation. Like the previous example, a tendency for estimation to be biased toward underestimation was lessened when information was received that corrected memory. As discussed earlier, the processes underlying telescoping might be quite different from the processes underlying estimation of task duration.

Although this shows that memory can be corrected with feedback, the underlying processes for the telescoping phenomenon might be so different that these results do not speak to the efficacy of this intervention on improving prediction.

In support of memory bias, it appears that feedback of previous duration lessens the tendency to underestimate event duration. Nonetheless, there is a need for more research in this area. In particular, experiments need to be conducted using feedback as an independent variable. A comparison in terms of accuracy should be made between participants who have memory corrected before prediction and participants who do not have memory corrected.

Conclusions and Implications

People tend to underestimate how long it will take to complete future tasks. Previous research has focused on the bias being due to memory not being correctly used. However, this view does not take into account what has been learned by research on retrospective time estimation. There is a general tendency to underestimate past event duration, which creates biased memories of duration that could, in turn, affect future planning.

We have reviewed a variety of sources of evidence that support the memory bias account of why people tend to underestimate future task duration. In particular, studies have shown that (a) there is a similar tendency to underestimate both past and future duration, (b) the tendency for underestimation is greater for familiar than for novel tasks, (c) variables that affect memory of duration affect prediction of duration in the same way, and (d) making memories of the past more salient does not affect prediction, whereas feedback of the actual duration of past events may eliminate underestimation. Not only does memory bias account for the existing data better than incorrect use of memory, but it also does so more parsimoniously.

Taken together, the results reviewed give a greater understanding of when underestimation is likely to happen: when tasks are familiar and long and there is motivation for quick completion. It may be that the majority of tasks for which duration is predicted fit into these three categories, which would explain why the tendency to underestimate is so general. This is especially true for estimations made in business and manufacturing.

People continue to underestimate future task duration even though they are aware of having done so numerous times in the past, seemingly unable to learn from their own history. Memory bias helps people understand why: People focus on the wrong cause of their underestimation. Bias in estimation of future duration is naturally perceived as due to failures in the predictive process. People receive feedback that their project was finished later than planned and know that their prediction was off. Indeed, the focus of previous research is on improving prediction by pointing out what information may be neglected during the process. The focus is rarely on the fact that there might be problems in our memory of duration. It is extremely rare that people receive information to let them know that their retrospective estimations of time are wrong. People assume that they are fairly accurate in estimating past duration even though they have received little if any information to validate this belief. Even if they are aware that they did not finish the task when planned, their memory of how long it took to complete the task itself might still be an underestimation of the actual duration. Consider a task with intervening events; someone might remember the task as taking less time than it actually took and blame his or her delay in completion on different causes such as other tasks that needed to be completed beforehand, being overly optimistic, or procrastination. Because people are unaware of the true cause of their underestimation, they are not able learn from their experience and correct future predictions.

The remedy is clear: Improve memory of duration. As can be seen from the results of the Buehler et al. (1997) and Loftus and Marburger (1983) studies, this may be an effective intervention. For important tasks, it may prove useful to keep records of beginning and ending times for the task to get an accurate idea of actual duration. If this process is repeated, then mean duration and variability can be computed from which more precise predictions can be made.

Although the evidence reviewed here lends support to a memory bias account for explaining underestimation of future duration, this does not mean that this is the only source of underestimation. Predictions of future task duration are complex and are likely to be multiply determined. It is likely that, at times, people are overly optimistic; they disregard their memories of past duration, they ignore the possibility that there might be interruptions or surprises, or they forget to plan for certain subtasks. All of these factors at times may cause or, at the very least, add to the tendency to underestimate future duration. For instance, it appears that when people are asked to think in detail about how they plan to finish a task, there is an even greater tendency to underestimate its duration (Buehler & Griffin, 2003). When focus during prediction is on the "inside view," as described in the planning fallacy (Kahneman & Tversky, 1979, 1982), the tendency to underestimate is exacerbated. However, there seems to be an additional, simple mechanism at the heart of underestimation: biased memory of past duration. This is not to say that other possible causes do not exist, only that the data suggest that the memory bias, by itself, can explain much of what goes wrong with prediction.

It is also possible that bias in prediction is still based on an optimistic outlook. Although the results indicate that people do use memory of past duration, the mechanism of optimism may still be the root cause of the tendency to underestimate. An optimistic outlook could cause people to remember an event as having taken less time than it actually did. For instance, people like to see themselves as always improving (Ross & Newby-Clark, 1998). This could explain why they are more likely to underestimate both past and future task duration for tasks that are familiar. Because they have performed the task a number of times, they assume that their performance must have improved and, therefore, they must have become faster. As a result, they remember the task as taking less time than it actually did. In turn, this leads to an underestimation of how long that task will take in the future.

However, it is not necessary for one to invoke an optimistic bias to explain the tendency to underestimate duration in retrospect. A number of theories can partially or wholly explain why, for instance, an increase in task duration can cause retrospective estimates to move from overestimation toward underestimation. It is possible that there is regression toward an average duration in which tasks shorter than this duration are overestimated, and tasks longer than this duration are underestimated (Fraisse, 1963). It could also be that the amount of information that a task contains or the number of changes in the task is not commensurate with the duration of the task. Short tasks may have proportionately more information or changes per unit of time than long tasks and, therefore, are overestimated while long tasks are underestimated (Block & Reed, 1978; Ornstein, 1969). Additionally, it may be that short tasks require more focused attention than do long tasks. This added attention to the task might take away from temporal attention, causing differences in estimation (Thomas & Weaver, 1975). Another possibility is that there are certain numbers that people are likely to round to when estimating duration, and the difference between these numbers grows larger with longer duration. This could lead to an increased tendency to underestimate with longer duration (Huttenlocher et al., 1990). In a different vein, Aschoff (1984, 1998) found in studies with participants in extended isolation that estimation of durations of 5 and 10 s was linked to the participant's body temperature, whereas estimation of durations of 1 hr or more was linked with the participant's sleep–wake cycle. This suggests that there might be differences in internal clocks that mediate short duration and long duration, with the possibility of one running fast and the other running slow. The ability to explain the results from the point of view of a number of different theories is further complicated by the fact that the results could be due to an interaction of a number of the above theories, because method of estimation may change with type of task (Jones & Boltz, 1989).

Although it is not clear why people underestimate past duration, it is clear that, at least for long tasks, people do. It appears that this bias is what leads us to underestimate future task duration. It is easy to see, then, why people continue to underestimate how long it will take to complete a paper or a home improvement project. Memories for the duration of similar tasks performed in the past are biased, causing people to believe that the task will take less time than it actually will.

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