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Is timely information always better? The effect of feedback frequency on decision making ☆

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ABSTRACT

Recent advances in information technology make it possible for decision makers to track information in real-time and obtain frequent feedback on their decisions. From a normative sense, an increase in the frequency of feedback and the ability to make changes should lead to enhanced performance as decision makers are able to respond more quickly to changes in the environment and see the consequences of their actions. At the same time, there is reason to believe that more frequent feedback can sometimes lead to declines in performance. Across four inventory management experiments, we find that in environments characterized by random noise more frequent feedback on previous decisions leads to declines in performance. Receiving more frequent feedback leads to excessive focus on and more systematic processing of more recent data as well as a failure to adequately compare information across multiple time periods. These results suggest that caution be used in the design and implementation of real-time information systems.

Recent advances in information technology have dramatically increased the speed at which information is delivered to decision makers and the speed with which decisions can be made. Examples include real-time stock quotes and the opportunity for investors to change their portfolios on a daily or hourly basis, constant updates on competitors' prices and the ability of marketers to rapidly match or beat these prices, and frequent updates on product demand and the possibility for managers to immediately change product order quantities in response.

From a normative sense, an increase in the frequency of feedback and the ability to make changes should enhance performance as decision makers are able to quickly respond to changes in the environment and see the consequences of their actions. Many believe that fast reactions to information are crucial to success. This belief has motivated large investments in technologies that provide real-time information to decision makers. However, given that people often adapt their decision-making processes to the information environment (Payne, Bettman, & Johnson, 1988), more frequent feedback may degrade performance if it leads decision makers to focus on, and more intensively process, the most recent in a set of data points and overreact to random noise. For example, frequent stock traders may react to price movements that are simply random (Gilovich, Vallone, & Tversky, 1985). Similarly, managers may fail to appreciate the randomness or dynamics of market demand for a product and end up chasing rising and falling demand (Schweitzer & Cachon, 2000; Sterman, 1989a).

Previous research has examined how feedback strength can help or hurt performance and learning (Hogarth, Gibbs, McKenzie, & Marquis, 1991), how delays between decisions and feedback hurt performance (Sterman, 1989b), how people learn with and without feedback (Camerer, 1997; Camerer & Ho, 1999; Weber, 2003), how noisy feedback inhibits learning (March, 1999), and how incentives impact performance and learning (Hogarth et al., 1991), but there has been little examination of how the *presentation* of feedback information affects decision making. In particular, there has been little attempt to understand how feedback frequency affects performance. In addition, although studies of choice often seek to link decision processes to outcomes (e.g., Bettman, Johnson, Luce, & Payne, 1993; Jarvenpaa, 1989; Lurie, 2004), research on feedback has tended to focus on outcome variables without explicitly examining the processes that lead to these outcomes. At the same time, previous research on decision processes (e.g., Bettman et al., 1993) has examined, how decision makers acquire and process exogenous information, such as attribute weights and values, rather than the decision maker's own, self-generated feedback. In addition,

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such process-tracing research has examined decisions in environments in which information is noise-free and where intensive information processing is associated with higher quality decisions. By examining how feedback frequency affects information acquisition, decision processes, and performance in noisy information environments this article provides an important link between the decision making and feedback literatures.

The primary goal of this article is to examine how feedback frequency affects performance. We focus our attention on noisy decision environments in which feedback is affected by random processes. Contrary to normative accounts, we find that more frequent feedback can lead to performance declines. Given this result, we seek to answer the following questions: Is there a point at which less frequent feedback does not improve performance? How does feedback frequency affect the type of information acquired and used for decision making? How do environmental factors such as profitability and demand variance impact the effect of feedback frequency on performance? How does introducing costs to making changes affect responses to feedback? What is the impact of coupling or decoupling feedback and decision epochs?

To address these issues, we examine the effect of feedback frequency on performance in four inventory management experiments. We use the well-known newsvendor problem, in which decision makers facing random demand need to decide how much of a product to order. The newsvendor problem is representative of many decision settings characterized by random fluctuations such as staffing for service industries, in which customer arrivals follow random patterns, or investments in financial markets, in which stock prices are characterized by random movements. Although the newsvendor problem is central to the stochastic inventory theory literature, more recently it has been used in the context of behavioral aspects of decision making (Schweitzer & Cachon, 2000). Feedback in the newsvendor problem is relatively straightforward, unlike that in dynamic environments which involve complex and varying levels of feedback (Diehl & Sterman, 1995; Paich & Sterman, 1993; Sterman, 1989b) and demand, although random, is drawn from the same distribution in every period and is not influenced by previous decisions. Importantly, the newsvendor problem has an optimal solution that provides a normative benchmark against which decisions can be judged. By studying feedback frequency in this environment, we are able to gain a clearer understanding of how and why feedback frequency affects performance.

In the first study, we show that, in an environment characterized by random noise, more frequent feedback can lead to declines in performance when demand variance is high. When demand variance is low, however, there are no significant effects of feedback frequency. Modeling decision makers' information use shows that more frequent feedback leads to greater weight on the most recent data received. To better understand and validate these results we conduct three additional studies. In the first of these, we manipulate the cost to making changes to order quantities and find that high change costs actually worsen the unfavorable effects of more frequent feedback. In the next study, we use process-tracing techniques and find that feedback frequency affects the type of information accessed as well as the pattern and selectivity of information acquisition. Decision makers who are provided more frequent updates access information on fewer rounds at a time, compare information within rounds, and are less selective in acquiring information; whereas those receiving less frequent updates access information on more rounds at a time, compare information across rounds, and are more selective in information acquisition. These results are important in that they suggest that the processes associated with superior performance in choice environments (Payne et al., 1988) may have the reverse effect in environments characterized by noisy feedback. In the final study, we establish that feedback frequency, rather than decision frequency, leads to declines in performance. Across all our studies, we find results consistent with earlier research (e.g., Schweitzer & Cachon, 2000) in which decision makers order less (more) than the optimal newsvendor quantity when the profit margin on the product is high (low).

In the following section, we review research on feedback and performance. Next, we describe our studies and the main observations. We conclude with a summary of our findings and possibilities for future research.

Feedback and performance

Feedback

Researchers have long been interested in the role of feedback (Annett, 1969; Bilodeau, 1966; James, 1890; Kluger & DeNisi, 1996) as well as the effects of different types of feedback (Balzer, Doherty, & O'Connor, 1989; Sengupta & Abdel-Hamid, 1993) on performance and learning. For a review of feedback research in engineering, biology, and the social sciences see Richardson (1991). Although early research on feedback generally argued that feedback led to learning and performance improvements (Annett, 1969; Kluger & DeNisi, 1996), more recent research has demonstrated that the effects of feedback are contingent on a number of individual, situational, and task characteristics as well as characteristics of the feedback itself (Balzer et al., 1989; Kluger & DeNisi, 1996). For example, Hogarth et al. (1991) found that medium levels of unfavorable outcome feedback (i.e., involving some losses rather than just gains) led to performance improvements relative to low levels of unfavorable feedback. However, when feedback was too exacting and deviations from optimality were more severely punished, performance was harmed as participants continued to experiment in an effort to improve. Some research has shown that determining which feedback variables to use is more important than the process used to evaluate these variables (Kleinmuntz, 1985). Others have shown that experience with a task does not always lead to performance improvements (Brehmer, 1980) and that outcome feedback, without cognitive feedback on the processes leading to these outcomes, can hurt learning in complex tasks (Balzer et al., 1989; Kluger & DeNisi, 1996). This is particularly true in dynamic environments characterized by feedback delays and nonlinearities in feedback strength (Brehmer, 1995; Diehl & Sterman, 1995; Lee, Padmanabhan, & Whang, 1997; Paich & Sterman, 1993; Sterman, 1989b). The contingent nature of feedback suggests that its effects depend on the interaction between feedback and the information environment.

Feedback frequency

Feedback frequency, as conceptualized here, refers to the number of trials for which one makes decisions and receives feedback at a time. Feedback is most frequent when a decision is made for a single trial followed by feedback on performance in that trial. Feedback is less frequent when a decision is made for a set of trials followed by feedback on performance in each of those trials. For example, a manager receiving frequent feedback might decide production levels at the beginning of the day and receive feedback on sales of her product that day. Alternatively, a manager receiving less frequent feedback might decide on production levels for the coming week and receive sales figures for each day of that week at the week's end. In this conceptualization, the number of trials, and the *amount of feedback information one receives*, is held constant; what varies is how often one makes decisions and receives feedback on these decisions. This is slightly different from conceptualizations of feedback frequency in which more frequent feedback was synonymous with more information; for example, research summarized in Bilodeau (1966), involved giving feedback for the third, sixth, and ninth trials, versus for each trial, and found that increasing the absolute number of feedback instances increased performance. However, these manipulations make it impossible to tell whether the effects were due to feedback spacing or to the amount of feedback provided. Relatedly, our conceptualization of feedback frequency does not involve presenting feedback from multiple periods using averages or other transformations that, in addition to changing the number of decisions for which feedback is provided, reduce feedback noise and the amount of feedback information provided. In other words, in this research, we focus on the way information is presented, rather than the amount or type of information provided to the decision maker.

Although related, there are also fundamental differences between our conceptualization of feedback frequency and feedback delay (Brehmer, 1995). In particular, feedback delay means that the decision maker must make decisions without the benefit of receiving feedback on earlier decisions; in our conceptualization of feedback frequency, decisions are made only after feedback on earlier decisions has been received. Thus, although feedback delay refers to the (constant) length of time before the effects of a decision are known, our conceptualization of feedback frequency refers to the length of time over which feedback is presented. This means that if feedback is received every five rounds, one has to wait five rounds to receive feedback on performance in the first trial but only one round to receive feedback in the fifth trial. In other words, feedback frequency is as much a characteristic of the way feedback information is presented as it is a characteristic of the time between decisions. Although feedback delay may hurt performance in dynamic environments, if delayed information is inadequately incorporated into future decisions (Sterman, 1989a, 1989b), the reverse may be true for feedback frequency, in which less frequent feedback reduces the likelihood of chasing noise.

Feedback and information use

By changing the way in which information is presented, feedback frequency may change its use by decision makers. In particular, previous research has shown that decision makers tend to use information consistent with its presentation (Bettman & Kakkar, 1977; Slovic, 1972). For example, organizing information by attribute leads decision makers to compare alternatives on attributes whereas presenting information by alternative leads to by-alternative processing (Bettman & Kakkar, 1977; Jarvenpaa, 1989; Payne, Bettman, & Johnson, 1993). Similarly, by differentially chunking the presentation of feedback information, changes in feedback frequency may alter the ways in which information is acquired and processed. For example, providing decision makers with multiple single rounds of feedback information may lead them to acquire information by round, and place greater weight on the most recent information; providing decision makers with the same feedback grouped over multiple rounds may lead to information acquisition and weighting more consistent with processing across rounds. In addition, more frequent feedback may lead to greater information acquisition and less selectivity in information processing since less information is presented in each set of feedback information. Although greater information acquisition and lower selectivity are generally associated with compensatory decision processes and higher performance in choice tasks (Payne et al., 1993), they may actually have detrimental effects in order-quantity tasks in which excessive attention to the wrong information may be harmful. In addition, to the extent that previous decisions serve as anchors for subsequent decisions (Sterman, 1989b), changes in feedback frequency may change the nature of these anchors. For example, providing feedback every round may provide decision makers with a single anchor whereas aggregating feedback across multiple rounds may offer multiple anchors for future decisions.

Studies

To examine the effects of feedback frequency on performance, we conducted four newsvendor experiments. The newsvendor problem is one of the basic models studied in inventory management and is applicable to a variety of settings including retailing and manufacturing (Swaminathan & Tayur, 2003). In the newsvendor problem, the decision maker chooses to order a quantity q before each selling period at a unit cost of c which she sells at a unit selling price $p > c$. A random demand is realized every period and any unsold item at the end of the period is salvaged at a price $s < c$. Stocks cannot be replenished during the selling period. The manager is assumed to be risk neutral and finds the quantity that maximizes the expected total profit at the end of the period. In a multi-period setting, this process is repeated every period. In our context, the newsvendor makes a decision and either receives feedback each round or does so for several rounds at a time. The profit maximizing order quantity (q) is given by

$$q = \boldsymbol{F}^{-1}\left(\frac{p-c}{p-s}\right) \tag{1}$$

where $\boldsymbol{F}$ is the distribution of demand and s is the salvage price. (For simplicity, in our studies s is set to 0.) The ratio $(p-c)/(p-s)$ is often referred to as the critical fractile and is the ratio of the shortage costs over shortage costs plus overage costs. This provides a normative benchmark for evaluating how close decisions are to optimality in a given environment. Within the newsvendor context we use four studies to examine the conditions under which feedback frequency affects performance, assess the generality of these findings, understand how feedback frequency affects decision processes as well as outcomes, and determine whether feedback or decision frequency drives these results. In each of the studies, we provide cognitive as well as outcome feedback (Balzer et al., 1989). In particular, participants receive cognitive information (CI) on the market demand, price, cost, and decisions that led to a given level of performance, in addition to detailed information on their performance in each round.

Experiment 1: Feedback frequency in high- and low-variance environments

Experiment 1 studies whether, and under what conditions, more frequent feedback affects performance. We were also interested in examining whether the effect of feedback frequency depends on the amount of randomness within the decision environment. In the newsvendor setting, to the extent that more frequent feedback leads to greater demand chasing, and therefore lower performance, these effects should be greater when there is greater variance in demand.

Method

Seventy-six undergraduate business students (juniors and seniors) participated for course credit in a computer-based experiment in which they chose inventory order quantities of "wodgets" over two 30-round periods. Participants were told that they were playing a decision-making game. In this game they were the retailer of a single product called a wodget. In each round they could purchase wodgets for 3 francs each and sell them for 12 francs each. (Wodgets and francs were used to increase the comparability between our results and those of Schweitzer & Cachon (2000) and to avoid potential income, familiarity, or other contextual effects from using real products priced in participants' home currency.) Participants were told this cost and price in every round.

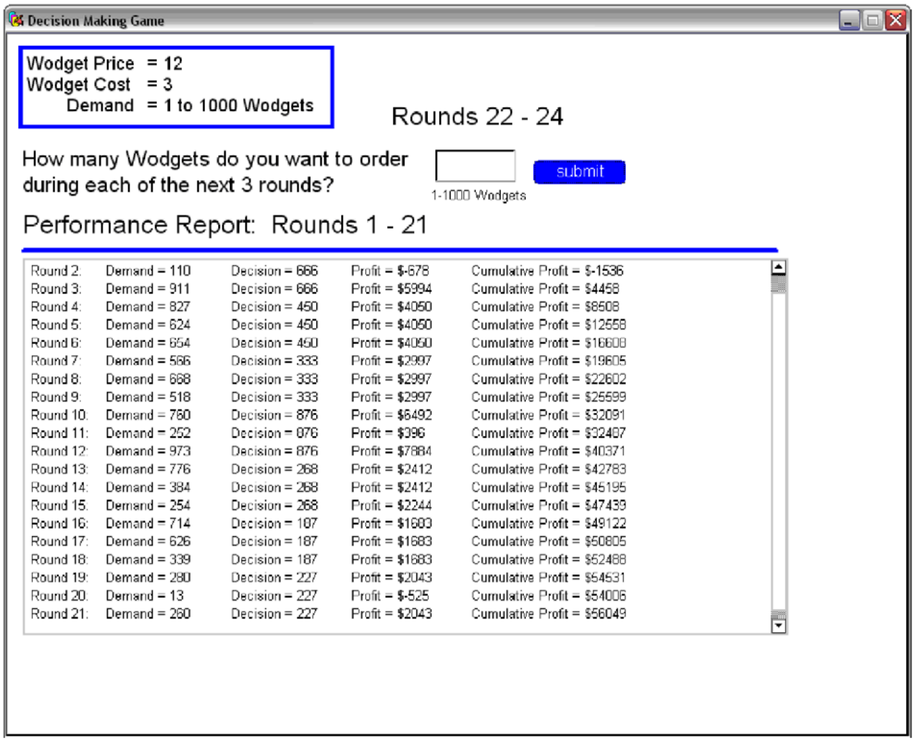

Fig. 1. Experiment 1 interface. *Note.* Feedback for a participant who received feedback every three rounds.

If demand exceeded the number of wodgets ordered in a round, all wodgets would be sold; however, if demand was less than the number of wodgets ordered, the unsold wodgets would be disposed of and could not be kept in inventory for subsequent rounds (i.e., the salvage price was 0 francs). Participants were told that their goal was to maximize profits in francs (see Schweitzer & Cachon (2000), for a similar procedure).

Participants were randomly assigned to one of three feedback frequency conditions. Depending on condition, participants made decisions and received feedback every round, every three rounds, or every six rounds. This manipulation of feedback frequency is akin to allowing managers to change inventory levels every day, twice a week or once a week (assuming a 6-day production schedule). Participants who received feedback every round were asked how many wodgets they wanted to order for that round. After placing their order, they were shown the demand for that round, the number of wodgets they ordered, the resultant profit, and their cumulative profit for the round. Those who received feedback every three (six) rounds were asked how many wodgets they wanted to order during each of the next three (six) rounds. In other words, the same order quantity was applied to the next three (six) rounds. After making their decision, they were shown the demand for each of those three (six) rounds, the profit in each round, and their cumulative profit in each round. This means that those who received feedback every round made 30 decisions in each 30-round period while those who received feedback every three or six rounds made 10 and 5 decisions, respectively, during each period. In all conditions, the total amount of feedback that participants received was the same; the only difference was whether the feedback was for a single round or a set of rounds. The information display showed feedback for up to 20-rounds at a time. Participants could scroll back to see feedback on all of their previous decisions. Fig. 1 shows the interface for a participant who received feedback every three rounds.

As in Schweitzer and Cachon (2000) high-profit condition, the price and cost settings used in the experiment gave a critical fractile of 75% = (12 − 3)/(12 − 0). In the high-variance condition, participants were told that demand was uniformly distributed between 1 and 1000. Following Schweitzer and Cachon, participants were told that consumer demand in each period was uncertain and that they could assume that there are 1000 balls in a bucket, labeled from 1 to 1000, and demand equals the number written on one ball which is randomly drawn from the bucket. In the low-variance condition, demand was uniformly distributed between 450 and 550. In the high-variance condition, the profit maximizing quantity was 750 = 75% × 1000, and in the low-variance condition, the profit maximizing quantity was 525 = (75% × 100) + 450. The expected profit from using the optimal order quantity was 3750 francs per round in the high-variance condition and 4425 francs per round in the low-variance condition. Within each variance condition, demand in each round was identical for all participants regardless of feedback frequency. All participants made decisions in both the high- and low-variance environments and the order was counterbalanced. Before beginning a new period, participants were told that they were now selling in a new market and that the price was still 12 francs but that the demand now ranged from 450 to 550 (1 to 1000). To control for participants' exposure to the newsvendor problem, we asked them if they had taken the core operations class in which the newsvendor problem was taught.

Results

Performance

Table 1 shows participants' performance under different experimental conditions. As expected, a repeated measures GLM analysis revealed that profits across the 30 rounds were higher in the low-variance than in the high-variance environment, 132.0 versus 99.7 (Wilks' $\lambda = .13$; $F(1, 70) = 479.57$, $p < .001$, $\eta_p^2 = .87$)[1]. More

[1] Performance is in thousands of francs. Statistical tests for all variables were conducted on the complete data.

Table 1
Performance in Experiment 1 (thousands of francs)

	Rounds	Low market variance condition first Frequency of feedback			High market variance condition first Frequency of feedback		
		Every round ($n = 14$)	Every 3 rounds ($n = 15$)	Every 6 rounds ($n = 14$)	Every round ($n = 11$)	Every 3 rounds ($n = 9$)	Every 6 rounds ($n = 13$)
High market variance	1–6	17.7	17.3	20.2	14.2	17.2	18.7
	7–12	24.6	25.3	26.7	19.7	24.6	25.0
	13–18	21.0	20.9	22.4	19.5	19.9	22.2
	19–24	13.2	12.4	12.6	12.6	11.6	13.4
	25–30	24.6	25.1	25.7	22.8	24.1	23.4
	Overall	101.1	100.9	107.6	88.8	97.5	102.7
	Optimal	119.8	119.8	119.8	119.8	119.8	119.8
Low market variance	1–6	26.7	26.8	27.0	26.7	27.0	26.9
	7–12	26.0	26.2	26.2	26.1	26.1	26.2
	13–18	26.6	26.5	26.6	26.7	26.6	26.5
	19–24	25.7	25.8	25.7	25.6	25.7	25.7
	25–30	26.9	26.6	26.8	26.9	26.8	26.7
	Overall	131.9	131.9	132.2	132.1	132.1	132.0
	Optimal	133.6	133.6	133.6	133.6	133.6	133.6

Note. Summed performance in 6-round increments, and for the 30 rounds combined, in thousands of francs. In the high market variance condition, demand was distributed uniformly from 1 to 1000; in the low-variance condition, demand was distributed uniformly from 450 to 550. Optimal performance is the overall performance if participants ordered the optimal quantity in each round.

importantly, results show that those who received feedback less frequently had higher performance than those who received more frequent feedback ($F(2, 70) = 3.74$, $p < .05$, $\eta_p^2 = .10$). Average 30-round performance was 118.6 for those who received feedback every six rounds versus 115.6 for those who received feedback every three rounds and 113.5 for those who received feedback every round. Planned contrasts showed a significant difference in performance between the 6-round and 1-round conditions ($F(1, 70) = 7.37$, $p < .01$) but not between the 6-round and 3-round conditions ($F(1, 70) = 2.44$, *ns*) or between the 3-round and 1-round conditions ($F(1, 70) = 1.14$, *ns*).

At the same time, the effect of feedback frequency on performance depended on the variance in market demand, as shown by a significant interaction between feedback frequency and market variance (Wilks' $\lambda = .89$; $F(2, 70) = 4.16$, $p < .05$, $\eta_p^2 = .11$). When the variance in market demand was high, average 30-round performance was significantly higher for those who received feedback every six rounds than for those who received feedback every three rounds or every round (means = 105.2, 99.2, and 94.9, respectively; $F(2, 70) = 3.96$, $p < .05$, $\eta_p^2 = .10$). When the variance in demand was low, however, differences in average 6-round performance between those who received feedback every six, three or every round were not significant (means = 132.1, 132.0, and 132.0, respectively; $F < 1$). These results suggest that more frequent feedback has detrimental effects in high-variance environments, but not in low-variance environments.

Finally, those who made decisions in a low-variance followed by a high-variance environment performed better than those who made decisions in a high-variance followed by a low-variance environment (means = 117.6 vs. 114.2; $F(1, 70) = 4.51$, $p < .05$, $\eta_p^2 = .06$). There was also a significant interaction of order and market variance (Wilks' $\lambda = .93$; $F(2, 70) = 5.48$, $p < .05$, $\eta_p^2 = .07$). In the high-variance market, those who first made decisions in the low-variance market performed better than those who first made decisions in the high-variance market (103.2 vs. 96.3; $F(1, 70) = 5.00$, $p < .05$, $\eta_p^2 = .07$). Differences in the low-variance market were not significant ($F < 1$).

Comparing participants' performance per 6-round increment (i.e., rounds 1-6, 7-12, 13-18, 19-24, 25-30) for each of the 30-round periods showed that participants improved their performance over time (Wilks' $\lambda = .11$; $F(4, 67) = 142.78$, $p < .001$, $\eta_p^2 = .90$) but that those who received feedback every round improved their performance more than those who received feedback every three rounds or every six rounds (Wilks' $\lambda = .70$; $F(8, 134) = 3.21$, $p < .01$, $\eta_p^2 = .16$). For example, differences between first and last 6-round performance for those who received feedback every round were greater (21.3 vs. 25.3) than differences for those who received feedback every three rounds (22.0 francs vs. 25.6) and those who received feedback every six rounds (23.2 vs. 25.6). As might be expected, there was also greater improvement in performance over time in the high-variance market than in the low-variance market (Wilks' $\lambda = .12$; $F(4, 67) = 122.15$, $p < .001$, $\eta_p^2 = .88$). Participants improved their performance over time the most when the market was characterized by high-variance in demand and feedback was given every round and the least when the market was characterized by low-variance in demand and feedback was given every six rounds (Wilks' $\lambda = .77$; $F(8, 134) = 2.31$, $p < .05$, $\eta_p^2 = .12$). In Experiment 1 and later studies, we found no significant differences between participants who had been exposed to the newsvendor problem by taking the core operations class and those who had not.

Order quantities

Fig. 2a shows average order quantities in each round in each of the experimental conditions as well as the optimal order quantities in these conditions. Fig. 2b illustrates how frequent feedback leads to demand-chasing behavior consistent with Schweitzer and Cachon (2000) results with second year MBA students familiar with the Newsvendor problem and its optimal solution. Like Schweitzer and Cachon we found that, in markets characterized by high profit margins, average order quantities across the 30 rounds were too low in the low-variance market, 511 versus the optimal 525 ($t(75) = -7.60$, $p < .001$, $r_{Y\lambda} = .65$), and in the high-variance market, 578 versus the optimal 750 ($t(76) = -12.72$, $p < .001$, $r_{Y\lambda} = .82$). As expected, the absolute value of the difference between optimal and actual order quantities was larger in the high-variance market than in the low-variance market (Wilks' $\lambda = .22$; $F(1, 70) = 255.94$, $p < .001$, $\eta_p^2 = .79$) and decreased over time (Wilks' $\lambda = .84$; $F(4, 67) = 3.31$, $p < .02$, $\eta_p^2 = .17$). Feedback frequency did not have a direct effect on the accuracy of order quantities but there was a

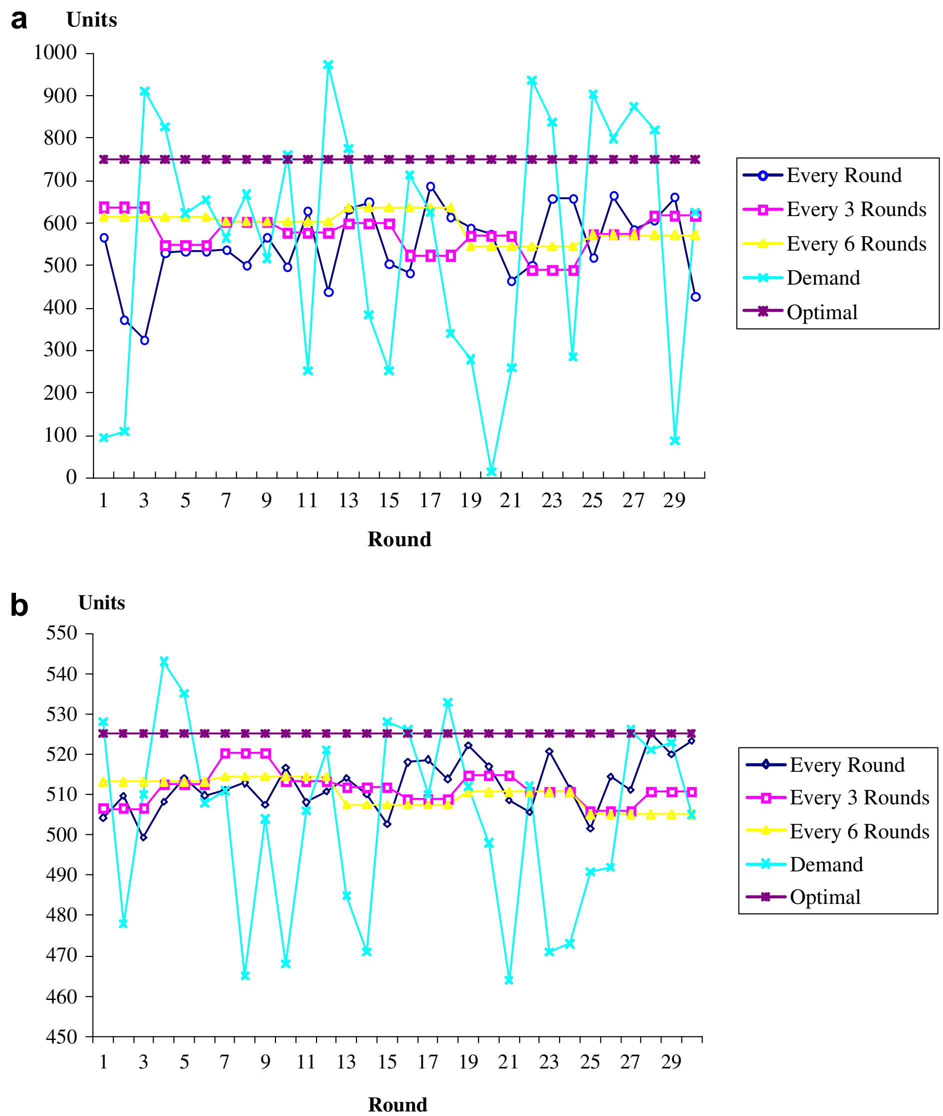

Fig. 2. (a) Decisions in high-variance environment in Experiment 1. (b) Decisions in low-variance environment in Experiment 1.

significant feedback by practice effect with increasing accuracy for those who received feedback every round or every 3 rounds but decreasing accuracy for those who received feedback every six rounds (Wilks' $\lambda = .73$; $F(8, 134) = 2.81$, $p < .01$, $\eta_p^2 = .14$). This suggests that, beyond a certain point, although it helps performance, less frequent feedback seems to hinder learning.

Feedback use in ordering decisions

We hypothesize that by changing the presentation of feedback information, changes in feedback frequency will affect the usage of this information. In particular, we predict that those who receive feedback every round will place a larger weight on feedback about the most recent round than those who receive feedback less frequently. Following others who have examined managers' use of different types of feedback information (e.g., Sterman, 1989b), we model ordering in Experiment 1 as:

$$O_t = \alpha_O O_{t-1} + \alpha_D(D_{t-1} - O_{t-1}) + \alpha_V V + \alpha_M M + \alpha_F F + \alpha_{DF} F(D_{t-1} - O_{t-1}) \quad (2)$$

where O_t is the quantity ordered at time t, $D_t - O_t$ is the difference between market demand and forecast demand at time t, V is the variance in market demand, M is a control for market order, F is the frequency of feedback, $F(D_t - O_t)$ is the interaction between feedback frequency and the difference between market demand and forecast demand at time t, α_O is a parameter that reflects the weight placed on the previous order, α_D is the weight placed on the deviation between actual and forecast demand (Holt, Modigliani, & Simon, 1955), α_V reflects the effects of being in a high- versus low-variance environment, α_M reflects potential market order effects, α_F reflects main effects of feedback frequency, and α_{DF} assesses differences between feedback conditions in terms of the relative weight assigned to differences between actual and forecast demand. From an anchoring and adjustment perspective (Sterman, 1989b; Tversky & Kahneman, 1974), α_O serves as a measure of the extent to which the decision maker anchors on their previous decision and α_D reflects the extent to which they adjust their decisions to the most recent feedback. A larger α_D indicates greater reliance on the most recent data. In order to compare the different feedback conditions, decisions in rounds 7, 13, 19, and 25 were regressed on feedback and previous decisions for rounds 6, 12, 18 and 24. Following previous research (e.g., Sterman, 1989a, 1989b), the multivariate data were restructured in univariate form to create 8 sets of independent and dependent variables for each of the 76 respondents for a total of 608 observations.

GLM analysis of the decision model specified in Equation 2 provides evidence for anchoring, as shown by the significant effect of previous decisions ($\alpha_O = .55$, $F(1, 599) = 167.64$, $p < .001$, $\eta_p^2 = .22$); as well as for adjustment, as shown by the significant impact of deviations between actual and forecast demand ($\alpha_D = .10$, $F(1, 599) = 23.07$, $p < .001$, $\eta_p^2 = .04$). Importantly, however, the extent to which participants changed order quantities based on discrepancies between their previous order and the most recent feedback varied as a function of feedback frequency ($\alpha_{DF} = .14$, $F(2, 599) = 9.56$, $p < .001$, $\eta_p^2 = .03$). In support of the prediction that more frequent feedback leads to greater weight being placed on recent data, separate analyses for each feedback frequency condition showed that the weight placed on the difference between realized and forecast demand was higher for those who received feedback every round ($B = .24$, $F(1, 599) = 34.48$, $p < .001$, $\eta_p^2 = .11$) than for those who received feedback every three rounds ($B = .00$, $F(1, 599) = .01$, *ns*) or those who received feedback every six rounds ($B = .10$, $F(1, 599) = 7.32$, $p < .01$, $\eta_p^2 = .05$).

Discussion

Results from Experiment 1 show, contrary to what might be expected from normative accounts, that more frequent feedback can actually lead to performance declines in noisy information environments. However, these unfavorable effects of more frequent feedback are only apparent in high-variance markets. In low-variance environments, feedback frequency does not have a significant effect on performance. Analysis of participants' decisions suggests that greater weight is placed on the most recent demand when feedback is given every round. Forcing participants to make a single decision for a series of rounds helps to reduce this tendency and, in the process, improves performance in high variance environments.

Our key findings in Experiment 1 relate to the detrimental effect of feedback frequency on performance and to differences in the way in which information is used. To assess the generalizability of our results, better understand the effect of feedback frequency on decision processes, and address alternative explanations, we conduct three additional studies. We address issues of generalizability in Experiment 2 by manipulating the cost associated with making changes to order quantities in both high- and low-profit markets. In Experiment 3, we use a process-tracing approach to provide a detailed understanding of how feedback frequency affects information acquisition and decision processes. Finally, we decouple feedback and decision epochs in Experiment 4 to determine whether it is feedback or decision frequency that leads to performance declines.

Experiment 2: Can the negative effects of frequent feedback be reduced by increasing the cost of making changes?

Whether changes are made to production lines or financial portfolios, there are often costs, either in time, money or effort, to make these changes. These costs may limit the harmful impacts of frequent feedback by reducing experimentation. Accordingly, Experiment 2 examined whether increasing the cost of making changes in order quantities would temper the tendency of decision makers' who receive frequent feedback to change order quantities based on the most recent feedback received. In addition, Experiment 2 tests whether the effects of feedback frequency found in high-profit environments also occur in low-profit environments (Schweitzer & Cachon, 2000). Low-profit environments may be characterized by greater losses than high-profit environments; and this may lead to greater effects of feedback frequency as decision makers engage in greater experimentation to avoid losses (Hogarth et al., 1991).

Method

Two-hundred fifty-three undergraduate business students participated for course credit in Experiment 2. The procedure was similar to Experiment 1 but participants chose inventory order quantities for one 30-round period instead of two 30-round periods. Participants were randomly assigned to experimental conditions defined by three between-subjects factors: Feedback frequency, cost of changing order quantities, and profit margin per unit sold. As in Experiment 1, feedback frequency was manipulated at three levels. Given that performance increased as feedback frequency decreased from every round to every three and every six rounds in Experiment 1, we chose a wider range of levels of feedback frequency in Experiment 2; namely, every round, every five rounds, or every 10 rounds. In particular, we were interested in seeing if there would be a point at which decreasing frequency of feedback would actually lead to declines in performance. This means that participants who received feedback every round made 30 decisions while those who received feedback every five or 10 rounds made six and three decisions, respectively.

The cost of making changes in order quantities was manipulated at two levels. In the low-cost condition, the cost of changing the order quantity was 50 francs. In the high cost condition, the cost of changing order quantities was 500 francs. This amount was the same irrespective of the amount of change in the order quantity and was applied whenever the order quantity differed from the previous decision. All participants incurred this cost for the first decision they made.

The profit margin on each wodget was also manipulated at two levels. In the high-profit condition, the selling price of each wodget was 12 francs and the cost of each wodget was 3 francs. In the low-profit condition, the selling price of each wodget was 12 francs and the cost of each wodget was 9 francs. The variance in demand ranged from 1 to 1000 wodgets in all conditions. This meant that the optimal order quantities were 750 ($75\% \times 1000$) in the high-profit condition and 250 ($25\% \times 1000$) in the low-profit condition (Schweitzer & Cachon, 2000).

Results

Performance

Table 2 shows summed performance, including the cost of making order quantity changes, and average order quantities across the 30 rounds and per 10-round block in the different experimental conditions. Because change costs impact performance, and because change costs may be greater for those who have the opportunity to change order quantities more frequently, we also analyzed the data after removing these costs. Like Schweitzer and Cachon (2000), we found that average profits were higher in the high-profit than in the low-profit condition, 93.0 versus −11.3, ($F(1, 241) = 2533.96$, $p < .001$, $\eta_p^2 = .91$). Comparing actual performance to that which could be achieved by choosing optimal order quantities shows that performance was significantly worse for those in the low-profit than in the high-profit condition, −96.5 versus −26.5, ($F(1, 241) = 1143.03$, $p < .001$, $\eta_p^2 = .83$). Replicating results from Experiment 1, a repeated-measures GLM shows that participants who received feedback and made decisions every round did worse, with change costs included, in terms of performance across the 30 rounds, than those who received feedback every five or every ten rounds, 35.4 versus 43.4 versus 43.8, respectively ($F(2, 241) = 6.82$, $p < .001$, $\eta_p^2 = .05$). Differences in performance were significant between those who received feedback every round and every five rounds ($F(1, 241) = 9.66$, $p < .01$) but not between those who received feedback every five and every ten rounds ($F < 1$). For those in the low-profit condition, and for whom the cost of making changes was low, those who received feedback every ten rounds

Table 2
Mean performance and average order quantities in Experiment 2

High-profit market	Cost of change = 50 Francs			Cost of change = 500 Francs		
	Frequency of feedback			Frequency of feedback		
	Every round (n = 20)	Every 5 rounds (n = 18)	Every 10 rounds (n = 36)	Every round (n = 31)	Every 5 rounds (n = 27)	Every 10 rounds (n = 16)
Performance (thousands)						
Rounds 1–10	30.0	32.6	30.6	28.4	33.1	31.6
Rounds 11–20	26.0	26.7	27.2	24.0	26.6	26.7
Rounds 21–30	37.0	34.4	35.8	34.3	36.7	36.3
Overall	93.9	93.9	93.7	90.9	97.9	95.3
Optimal	119.7	119.7	119.7	119.3	119.3	119.3
Order quantities (Optimal 750)						
Rounds 1–10	439.8	486.9	460.4	423.7	544.4	505.2
Rounds 11–20	530.2	534.7	599.3	496.1	602.1	600.0
Rounds 21–30	588.0	511.8	558.5	522.4	586.0	571.9
Overall	519.3	511.2	539.4	480.7	577.5	559.0
Low-profit market	(n = 17)	(n = 13)	(n = 13)	(n = 12)	(n = 21)	(n = 29)
Performance (thousands)						
Rounds 1–10	−6.1	−5.1	−8.5	−8.0	−6.3	−2.7
Rounds 11–20	−5.2	−1.7	−2.9	−10.0	−1.8	−1.0
Rounds 21–30	−1.9	0.4	0.8	−7.00	−1.9	1.4
Overall	−12.8	−6.2	−10.6	−20.9	−8.3	−1.4
Optimal	85.5	85.5	85.5	85.0	85.0	85.0
Order quantities (Optimal 250)						
Rounds 1–10	399.3	337.5	419.3	396.8	389.0	280.5
Rounds 11–20	365.6	257.1	328.5	439.4	281.3	248.9
Rounds 21–30	296.0	220.2	248.9	414.9	342.1	206.4
Overall	353.6	271.6	332.2	417.1	337.5	245.3

Note. Performance is in thousands of francs per 10-round increment, and across the 30 rounds, including change costs. Order quantity is the average order quantity per 10-round increment, and across the 30 rounds. The optimal order quantity was 750 wodgets in the high-profit market and 250 wodgets in the low-profit market. Optimal performance is the overall performance, including change costs, if participants ordered the optimal quantity in each round.

actually did worse than those who received feedback every five rounds, suggesting that there may be a point at which decreasing feedback frequency is actually harmful. Results were similar when change costs were not included when calculating overall performance. More frequent feedback led to lower performance with overall performance levels of 37.8, 44.3, and 44.3 when feedback was given every one, five, and ten rounds, respectively ($F(2, 241) = 4.52$, $p < .02$, $\eta_p^2 = .04$). This provides further evidence that more frequent feedback can lead to performance declines.

Increasing the cost to change order quantities from 50 to 500 francs did not have a significant effect on performance ($F < 1$) but did interact with feedback frequency ($F(2, 241) = 3.80$, $p < .03$, $\eta_p^2 = .03$; see Fig. 3). An increase in the cost of making order quantity changes led to worse performance when feedback was provided every round, 30.8 versus 40.0 ($F(1, 241) = 6.26$, $p < .02$, $\eta_p^2 = .03$), but did not significantly affect overall performance when feedback was provided every five rounds (means = 43.2 vs. 43.6; $F < 1$) or every ten rounds (means = 46.1 vs. 41.5; $F(1, 241) = 1.79$, *ns*). Similar results were found when change costs were not included in overall performance. It thus appears that increasing the cost of making order quantity changes does not mitigate the harmful effects of more frequent feedback.

To better understand the relationship between feedback frequency and change cost, we assessed the extent to which participants changed order quantities in the different conditions. To allow the changes in order quantities to be compared across different feedback conditions, the total number of changes in each 10-round block were divided by the number of possible changes, (i.e., 1 for those who received feedback every ten rounds). Results show a significant effect of feedback frequency ($F(2, 241) = 105.16$, $p < .001$, $\eta_p^2 = .47$). Those who received feedback every round made a greater percent of possible changes in order quantities than those who received feedback every five rounds, 30% versus 23% of possible changes ($F(1, 241) = 4.57$, $p < .05$), but a lower percent of possible changes than those who received feedback every ten rounds, (30% vs. 70%; $F(1, 241) = 128.01$, $p < .001$). As expected, those for whom the cost of making changes in order quantities was 50 francs per change made more changes than those for whom the cost was 500 francs per change, 47% versus 35% ($F(1, 241) = 16.68$, $p < .001$, $\eta_p^2 = .07$). More importantly, there was a significant interaction of feedback frequency and change cost ($F(2, 241) = 7.76$, $p < .01$, $\eta_p^2 = .06$) with greater cost having a larger effect on reducing the percentage of changes when feedback was given every ten rounds (56% vs. 84%; $F(1, 241) = 32.27$, $p < .001$), than when feedback was given every five rounds (21% vs. 24%; $F < 1$), or every round (28% vs. 33%; $F(1, 241) = 1.03$, *ns*).

Order quantities

Like Schweitzer and Cachon (2000), we found that average order quantities across the 30 rounds were too high in the low-profit market, 315 versus the optimal 250, ($t(104) = 5.16$, $p < .001$, $r_{Y\lambda} = .45$); and too low in the high-profit market, 530 versus the optimal 750, ($t(147) = -17.08$, $p < .001$, $r_{Y\lambda} = .82$). The extent to which participants placed non-optimal order quantities, however, depended on the interaction between the profitability of the market and the frequency of feedback ($F(2, 241) = 5.68$, $p < .01$, $\eta_p^2 = .05$). In the high-profit market, order quantities were significantly lower than the optimal level in all feedback frequency conditions. In the low-profit market, however, order quantities were significantly higher than optimal when feedback was given every round ($t(28) = 6.26$, $p < .001$, $r_{Y\lambda} = .76$), or every five rounds ($t(33) = 3.24$, $p < .01$, $r_{Y\lambda} = .49$), but not significantly higher than

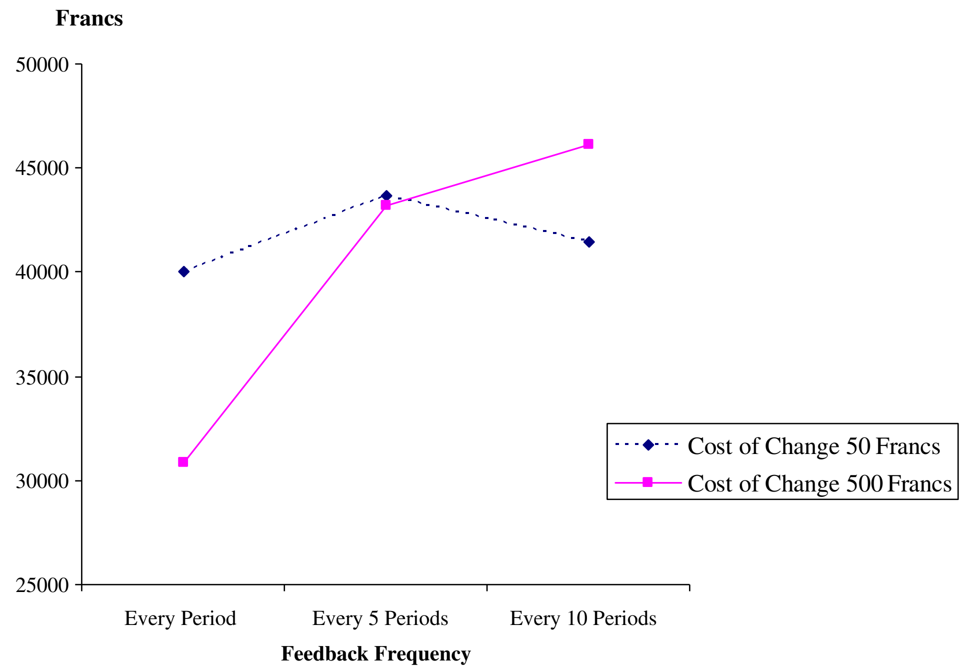

Fig. 3. Overall 30-round profits in Experiment 2.

optimal when feedback was given every ten rounds ($t(41) = 1.05$, *ns*). Feedback frequency did not have a significant main effect on order quantities.

Discussion

Results from Experiment 2 replicate those of Experiment 1; namely, that more frequent feedback can lead to declines in performance. Results show that these effects are robust in both low- as well as high-profit markets, suggesting that the effects are generalizable to situations in which decision makers receive unfavorable (loss) as well as favorable (gain) feedback. Surprisingly, increasing the cost of making changes to order quantities did not alleviate the performance declines from more frequent feedback, suggesting that more frequent feedback leads participants to act on it, despite the cost of doing so.

Two additional findings of Experiment 2 bear discussion. First, the effects of feedback frequency on choosing optimal order quantities depend on market conditions. Although we observed Schweitzer and Cachon (2000) "too high" phenomenon in the low-profit market when feedback was given every round, the difference between actual and optimal order quantities became non-significant when feedback was given every ten rounds. This suggests that losses experienced in the low-profit market led to more corrective behavior, with harmful effects for those who received more frequent feedback and helpful effects for those who received less frequent feedback. The second additional finding of Experiment 2 was that, beyond a certain point, decreasing levels of feedback did not help performance. In particular, reducing feedback from every five to every 10 rounds did not enhance performance. This finding is important in that it suggests there may be an optimal level of feedback frequency. This question is further examined in Experiment 4.

Experiment 3: Process-tracing study

The purpose of Experiment 3 is to gain insight into how feedback frequency affects decision processes as well as outcomes. In particular, by changing the way in which information is presented, feedback frequency may change the nature of the decision task and therefore the way in which decisions are made (Payne et al., 1988). Task variables are general characteristics of information environments and include the amount of information presented to decision makers and how the decision maker can interact and respond to information; context variables refer to data values specific to a given decision problem (Bettman et al., 1993; Lurie, 2004). Task variables tend to have the greatest effect on decision strategies whereas context variables tend to have the greatest effect on the relative performance of alternative strategies (Bettman et al., 1993).

Process-tracing methods such as Mouselab (Payne et al., 1988), eye tracking (Russo & Dosher, 1983), or verbal protocols (Jarvenpaa, 1989) may be used to assess the way in which decisions are made. In particular, processing effort, the extent to which decision makers are selective in the amount of time they spend evaluating different types of information, and the extent to which decision makers process information by rows (i.e., examine multiple pieces of information for a single decision) versus by columns (i.e., examine the same piece of information for multiple decisions) provide insights into the processes that lead to decisions. For example, non-compensatory decision processes, in which decision makers tend to make comparisons on a single piece of information (or aspect; Tversky, 1972), are associated with greater selectivity in processing as well as by-attribute processing, in which alternatives are compared on a single attribute at a time. In the newsvendor setting, non-compensatory processes are indicated by comparisons on a single piece of information (e.g., demand in the previous period) across multiple rounds whereas compensatory processes are indicated by the examination of all of the feedback information for one round at a time. In traditional choice environments, compensatory decision processes are associated with higher quality decisions than non-compensatory processes since each alternative is evaluated separately on each attribute (Payne et al., 1988). However, in noisy feedback environments, compensatory decision processes may reduce decision quality through increased attention to single observations and inadequate comparisons across rounds of feedback information.

Method

Design and procedure

In Experiment 3, participants made ordering decisions and received feedback using an information acquisition system similar to Mouselab (Bettman, Johnson, & Payne, 1990; Lurie, 2004; Payne et al., 1988) that was developed specifically for this study. Previous research has shown that patterns of information acquisitions in Mouselab are similar to those in eye-tracking studies (Lohse & Johnson, 1996). The experimental setup was identical to the high-variance condition of Experiment 1 and, to allow comparisons with Experiments 2 and 4, participants were randomly assigned to make decisions and receive feedback every round or every five rounds during one 30-round period. Twenty-seven undergraduate students were paid $7 each to participate in this 20 minute study. As in Experiment 1, the profit per wodget sold was high with participants being able to buy and sell wodgets for 3 and 12 francs, respectively. As in Experiment 1, the optimal order quantity was 750 wodgets per round.

Fig. 4 shows the information acquisition system used in Experiment 3. The underlying information and display format was similar to that of the other studies but, in order to capture participants' information acquisition processes, feedback information (with the exception of round and column labels) was hidden by opaque boxes. Moving the mouse cursor over a box revealed its contents, and the information remained visible until the cursor was moved out of the box. Information was available for only one box at a time. Separate boxes were used for each piece of information (i.e., demand, order quantity, profit, and cumulative profit) for each round. This allowed the order in which information was accessed and the time spent accessing each piece of information for each round of feedback to be recorded. As in Experiments 1 and 2, feedback for each round was displayed on a separate line. Boxes were added to the display along with feedback information so that the number of boxes always equaled the number of pieces of feedback information that were available. For example, if five rounds of feedback information were available, there would be 20 boxes with four boxes per round of feedback, one for each piece of information. No scrolling was necessary to see feedback on previous rounds. Before beginning to make ordering decisions, participants practiced using the information acquisition system.

Dependent variables

In addition to the dependent measures used in Experiments 1 and 2, Experiment 3 included nine measures that assessed the amount and time spent acquiring feedback information, the type of information accessed, selectivity in the access of information, and the pattern in which information was accessed. As in previous process-tracing studies, to avoid recording mouse movements that did not involve data acquisition, accesses of less than 200 ms were not tracked (J.R. Bettman, personal communication, October 10, 2005). Measures of the amount and time spent accessing feedback information included the number of acquisitions, the percent of available information accessed, the average time per acquisition, and the number and percent of available rounds accessed. Differences in the type of information accessed were assessed by comparing the proportion of time spent on each type of feedback information (demand, order quantity, profit, and cumulative profit) in each condition. Processing selectivity was measured through the variance in time spent per round of feedback and the variance in time spent per type of feedback information. The pattern of information acquisition was measured as the extent to which information was accessed by round or by information type. See Payne et al. (1993) and Lohse and Johnson (1996) for these and similar mea-

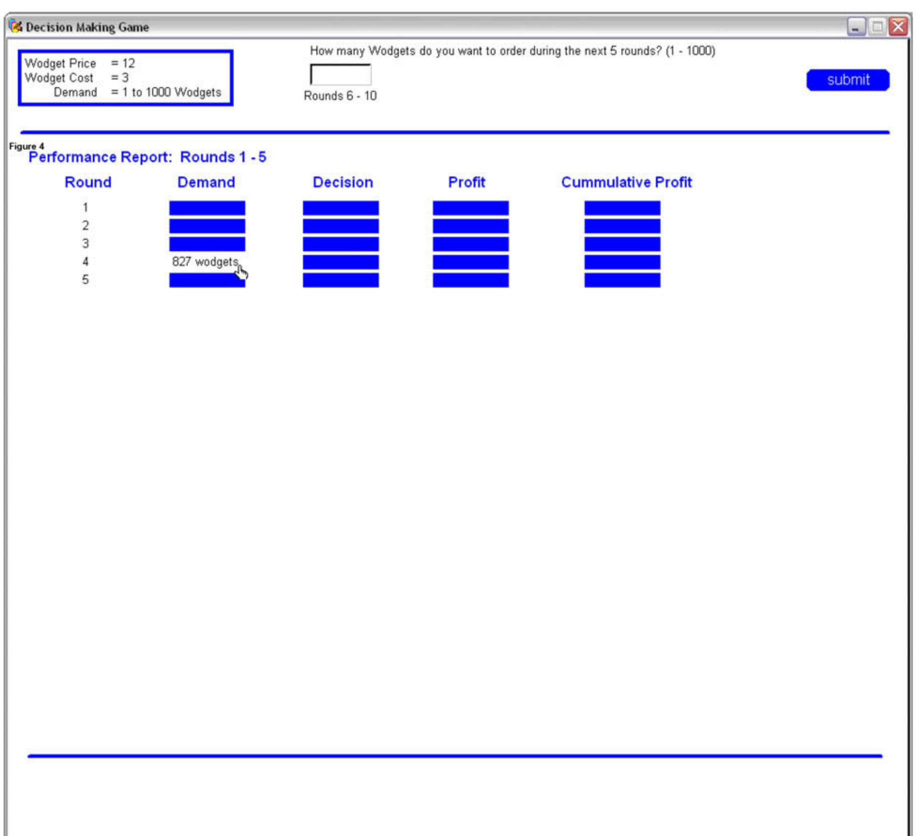

Fig. 4. Experiment 3 interface. *Note*. In Experiment 3, to allow information acquisitions to be tracked, feedback information was covered by boxes that became transparent when moused over. Shows feedback after the initial decision by a participant who received feedback every five rounds.

sures of decision-making processes. Table 3 summarizes the results of Experiment 3.

Results

Performance

As in Experiments 1 and 2, more frequent feedback had a deleterious effect on performance. In particular, those who received feedback every round made less profit across the 30 rounds (92.5) than those who received feedback every five rounds (105.6; $F(1, 25) = 6.72$, $p < .05$, $\eta_p^2 = .21$).

Order quantities

As in Experiment 1, order quantities were too low in this high-profit market, 577 versus 750; $t(26) = -5.52$, $p < .001$, $r_{Y\lambda} = .73$. At the same time, those who received feedback every five rounds placed orders that were not significantly different from the optimal order quantity, 672 versus 750; $t(11) = -1.60$, *ns*, whereas those who received feedback every round placed orders that were significantly lower than the optimal, 502 versus 750; $t(14) = -8.47$, $p < .001$, $r_{Y\lambda} = .91$.

Information acquisition

Acquisitions were calculated as the number of boxes opened per five-round increment. Average time per acquisition was calculated by dividing the number of acquisitions by the amount of time that boxes were open. The percent of available information acquired was determined by dividing the number of unique boxes opened by the number of unique boxes available after each decision. The number of rounds accessed after each decision and the percent of available rounds accessed were also calculated.

Results show that those who received feedback every round made more acquisitions per 5-round increment (average 25.2) than those who received feedback every five rounds (average 20.5) but this difference was not statistically significant ($F(1, 25) = 1.30$, *ns*). Differences in the average time per acquisition for those who received feedback every round (1.7 s) were not significantly different from those who received feedback every five rounds (1.6 s; $F < 1$). Importantly, however, those who received feedback every five rounds acquired a greater percent of the available information after each decision than those who received feedback every round (31% vs. 15%; $z = 4.34$, $p < .001$), acquired information from more rounds at a time (5.7 vs. 2.0 rounds; $F(1, 25) = 49.91$, $p < .001$), and accessed information on a greater percent of available rounds (46% vs. 22%; $z = 3.76$, $p < .001$).

Table 3
Performance and process measures in Experiment 3

	Every round ($n = 15$)	Every 5 rounds ($n = 12$)
Performance (thousands)		
Rounds 1–5	10.9	12.2
Rounds 6–10	22.1	23.3
Rounds 11–15	15.2	16.8
Rounds 16–20	11.0	11.6
Rounds 21–25	15.6	19.2
Rounds 26–30	17.8	22.4
Overall	92.5	105.6
Optimal	119.8	119.8
Average order quantity (optimal 750)	501.8	671.9
Average number of acquisitions	25.2	20.5
Time per acquisition (s)	1.7	1.6
Percent of information acquired	15%	31%
Average rounds of feedback acquired	2.0	5.7
Percent of time on feedback about		
Previous demand	44%	38%
Previous decisions	14%	8%
Profit per round	17%	14%
Cumulative profit	25%	40%
Variance in acquisition time per round	2.05	3.97
Variance in acquisition time per type of feedback	2.28	15.51
Acquisition pattern	.41	−.49

Note. Performance is in thousands of francs per 10-round increment, and across the 30 rounds, including change costs. Optimal performance is the overall performance if participants ordered the optimal quantity in each round. Average order quantity is the average order quantity across the 30 rounds. The optimal order quantity was 750. Average number of acquisitions is the average number of times that information boxes were opened following feedback. Time per acquisition is the average time spent acquiring information divided by the number of boxes opened. Percent of information acquired is the average proportion of available information boxes opened. Average rounds of feedback acquired is the average number of rounds for which information was acquired after each decision. Percent of time is the proportion of time spent on each of the four types of feedback information available. Variance in acquisition time per round is the average variance in acquisition time across rounds. Variance in acquisition time per type of information is the average variance in acquisition time across the four types of feedback information. Acquisition pattern ranges from −1 to +1 with positive numbers indicating greater within round (row-based) information acquisition and negative numbers indicating greater within information type (column-based) information acquisition.

Type of information acquired

Participants spent the largest proportion of time acquiring feedback information about previous demand (39% of time), followed by information about cumulative profit (34% of time), profit in a given round (16% of time), and previous order quantities (11% of time). Comparison of the proportions of time spent on each column of information shows that those who received feedback every round spent a larger proportion of time accessing information about their previous decisions than those who received feedback every five rounds (14% vs. 8%; $z = 2.88$, $p < .01$), but spent less time accessing information about cumulative profits (25% vs. 40%; $z = 2.83$, $p < .01$). Differences in the proportion of time spent on demand and per-round profit information were not significant.

Processing selectivity

Measures of processing selectivity were created by measuring the mean variance in time spent acquiring information per round and per information type. Greater selectivity (higher variance in time per round or attribute) is indicative of non-compensatory processing whereas lower selectivity is indicative of more compensatory processing (Lohse & Johnson, 1996; Payne et al., 1988). Analysis showed greater selectivity (higher variance) in acquisition time per round by those who received feedback every five rounds than those who received feedback every round (variance = 3.97 vs. 2.05; $F(1, 25) = 4.64$, $p < .05$, $\eta_p^2 = .16$). Similarly, those who received feedback every five rounds were more selective in the time they spent acquiring information about demand, previous decisions, profit per round, and cumulative profits than those who received feedback every round (variance = 15.51 vs. 2.28; $F(1, 25) = 13.51$, $p < .001$, $\eta_p^2 = .35$).

Acquisition pattern

Moving the mouse along a row of feedback information for a given round (e.g., from feedback about demand in round 5 to feedback about the amount ordered in round 5) was coded as a round-based transition. Moving the mouse along a column for a particular type of feedback information (e.g., from feedback about demand in round 5 to feedback about demand in round 4) was coded as an information type-based transition. To assess the extent to which feedback was accessed by round or by information type, an index of round-versus information type-based transitions was created by taking the number of round-based transitions, minus the number of information type-based transitions, and dividing by the sum of round- and information type-based transitions (Payne, 1976). This index ranges from −1 (indicating only information type-based processing) to +1 (indicating only round-based processing). Results show those who received feedback every five rounds generally acquired information by information type for multiple rounds at a time (pattern = −.49) whereas those who received feedback every round generally acquired information within each round separately (pattern = .41; $F(1, 25) = 50.23$, $p < .001$, $\eta_p^2 = .64$).

Discussion

Results from Experiment 3 help explain why an increase in feedback frequency leads to performance declines. Although decision makers are free to access feedback on all previous rounds regardless of feedback frequency, they tend to limit their information access to the most recent set of presented data. However, the selectivity and processing pattern results suggest that it is not simply that participants focus on new information; rather, that they process the information in very different ways. In particular, more frequent feedback led to greater processing by round than by information type and lower selectivity in information processing suggesting more compensatory decision processes (Payne et al., 1988). Although lower selectivity and more compensatory decision processes are generally associated with higher performance in choice tasks (since decision makers make more complete use of information), in the task studied here, for which there was a random component to feedback, this more systematic processing of information decreased performance. Finally, those who receive more frequent feedback focused more attention on their previous decisions; those who receive feedback less frequently spent more time examining information about their cumulative profits. In sum, the results from Experiment 3 show that feedback frequency not only changes the amount and type of information that decision makers acquire but also the way in which this information is processed.

Experiment 4: Decoupling feedback frequency from decision frequency

In Experiments 1 through 3, participants made a single decision for one or multiple rounds at a time. For example, in Experiment 1, those who received feedback every round made 30 decisions in 30 rounds whereas those who received feedback every three or six rounds made ten and five decisions, respectively. Although feedback and decision frequency often co-occur, there are situations in which they may be decoupled. For example, investors may make a series of investments over a period of time and wait to evaluate the wisdom of these different decisions until receiving feedback in the form of a quarterly statement. Similarly, managers who are uncertain about product demand may decide to produce a different amount each day; yet receive complete information on realized demand only once a week.

We have argued that increasing feedback frequency changes the information that decision makers attend to, leading them to examine fewer rounds of data at a time, and be more likely to chase demand; this lowers their performance. An alternative explanation is that the results are due to reducing the number of decisions that participants can make. In other words, performance declines by those who get more frequent feedback are due not to feedback frequency but rather to decision frequency. To examine this possibility, Experiment 4 manipulated feedback and decision frequency independently.

Method

The procedure for Experiment 4 was similar to Experiments 1 through 3 but half of the participants made separate decisions for each round instead of a single decision for multiple rounds. For example, when feedback was given every six rounds, participants were either asked to choose one order quantity for the next six rounds or were asked to make separate decisions for each of the next six rounds. To separate the effects of feedback and decision frequency, those who received the most frequent feedback were given feedback on two rounds (rather than one) at a time. That is, providing feedback after every round, which is the standard newsvendor setup, makes it impossible to determine whether feedback or decision frequency drives the results. To the extent that receiving feedback every round leads to the strongest focus on demand in the previous round, and therefore the largest impact on performance, setting the most frequent feedback to every two rounds should weaken our results.

Feedback frequency was manipulated at three levels between subjects. Following Experiment 2, to see if beyond a certain point decreasing levels of feedback frequency lead to performance declines, a wider range of levels of feedback frequency was used in Experiment 4. This led to feedback frequency conditions of every two rounds, every six rounds, or every ten rounds. We used a low-profit environment as a further test of the generalizability of our findings. As in the low-profit condition of Experiment 2, the optimal order quantity was 250. One hundred thirty-five undergraduate students participated in Experiment 4 for course credit. Participants were randomly assigned to one of the six experimental conditions.

Results

Performance

Table 4 summarizes the results of Experiment 4. Results show a marginal effect of feedback frequency ($F(2, 129) = 2.51$, $p < .10$, $\eta_p^2 = .04$). This marginal effect may be due to the fact that those who received the most frequent feedback received feedback every two rounds rather than each round at a time. Importantly, polynomial contrasts found a significant quadratic effect of feedback frequency ($F(1, 129) = 4.88$, $p < .05$) showing that, beyond a certain point, decreasing levels of feedback lead to performance declines. Linear effects were not significant. Average overall 30-round performance was 3.5 thousand francs for those who received feedback every 10 rounds versus 6.5 thousand francs for those who received feedback every six rounds and 3.8 thousand francs for those who received feedback every two rounds. Planned comparisons showed a significant difference in performance between the 6-round and 10-round conditions ($F(1, 129) = 4.01$, $p < .05$) and a marginal difference between the 6-round and 2-round conditions ($F(1, 129) = 3.53$, $p < .10$). Differences between the 2-round and 10-round conditions were not significant ($F(1, 129) = .04$, *ns*). There was no significant effect of decision frequency ($F(1, 129) = .00$, *ns*) and the interaction of feedback and decision frequency was also not significant ($F(1, 129) = .18$, *ns*), clearly showing that feedback frequency, rather than decision frequency, leads to differences in performance.

Order quantities

Like Schweitzer and Cachon (2000) we found that, in markets characterized by low profit margins, average order quantities across the 30 rounds were too high, 419 versus 250 ($t(134) = 15.45$, $p < .001$, $r_{Y\lambda} = .80$). Feedback frequency did not have a significant effect on the accuracy of order quantities but there was a marginal effect of decision frequency with order quantities that were closer to optimal when separate decisions were made for each round (398 vs. 441; $F(1, 129) = 3.83$, $p < .10$, $\eta_p^2 = .03$). The interaction of feedback and decision frequency was not significant.

Table 4
Experiment 4 results

	Same decision for multiple rounds			Separate decisions for each round		
	Every 2 rounds (n = 21)	Every 6 rounds (n = 19)	Every 10 rounds (n = 24)	Every 2 rounds (n = 28)	Every 6 rounds (n = 25)	Every 10 rounds (n = 18)
Performance (thousands)						
Rounds 1–6	−2.3	−0.5	–	−1.7	−0.4	–
Rounds 7–12	4.0	4.7	–	4.2	3.7	–
Rounds 13–18	2.5	2.4	–	1.7	2.2	–
Rounds 19–24	−3.9	−3.0	–	−2.9	−2.4	–
Rounds 25–30	3.1	3.4	–	2.8	2.8	–
Rounds 1–10	1.7	–	3.0	2.0	–	2.9
Rounds 11–20	−2.6	–	−4.0	−1.7	–	−3.3
Rounds 21–30	4.2	–	4.4	3.9	–	4.0
Overall	3.6	6.9	3.4	4.1	6.0	3.5
Optimal	85.5	85.5	85.5	85.5	85.5	85.5
Order Quantities (optimal 250)						
Rounds 1–6	339.7	415.0	–	323.3	407.8	–
Rounds 7–12	429.5	421.6	–	435.1	399.6	–
Rounds 13–18	431.8	472. 9	–	423.2	421.9	–
Rounds 19–24	407.1	410.5	–	375.8	406.8	–
Rounds 25–30	431.1	417.6	–	415.0	336.8	–
Rounds 1–10	372.2	–	473.0	363.0	–	410.5
Rounds 11–20	441.0	–	526.3	426.6	–	443.0
Rounds 21–30	410.3	–	461.3	393.8	–	362.3
Overall	407.8	427.5	486.8	394.5	394.6	405.3

Note. Performance is in thousands of francs per 6- or 10-round increment, and summed across the 30 rounds. Optimal performance is the overall performance if participants ordered the optimal quantity in each round. Order quantity is the average order quantity per 6- or 10-round increment, and across the 30 rounds. The optimal order quantity was 250 wodgets.

Discussion

Experiment 4 establishes that feedback frequency, rather than decision frequency, influences performance. Although one might argue that constraining the number of decisions that one can make might explain the results of Experiments 1 through 3, results from Experiment 4 do not support this explanation. Regardless of whether one makes a single decision for multiple rounds or one decision for each round, it is the way in which feedback is presented that matters. In addition to showing that feedback frequency is more important than decision frequency, Experiment 4 also shows that, beyond a certain point, decreased feedback frequency can lead to performance declines.

Conclusions and discussion

New information technologies are rapidly changing the decision-making environment. Such technologies promise to lower costs and improve performance by providing managers with minute-by-minute feedback and the ability to quickly make changes to adapt to varying conditions. At the same time, there have been few attempts to examine how increasing the frequency of feedback influences managerial performance. This research is an initial attempt to understand these effects within the well-known framework of the newsvendor problem. Our results reinforce the need to test the behavioral implications of new technologies, systems, and processes. Although information sharing and frequent updates are expected to lead to better performances under normative assumptions (Gavirneni, Kapuscinski, & Tayur, 1999; Swaminathan & Tayur, 2003), we find that more frequent updates of information are not necessarily good. Like statistical process control charts designed to help managers avoid overreacting to minor changes in performance (Schwarz, 2007) and decision rules that average across forecasts to smooth production (Holt et al., 1955), less frequent feedback may help managers make better decisions.

Results from Study 1 show that those who received more frequent feedback had lower levels of performance than those who received less frequent feedback, but only in high-variance environments. Further, using a linear model, we found that those who received more frequent feedback placed greater weight on information about market demand in the previous round than those who received less frequent feedback. Study 2 shows that increasing levels of feedback leads to performance declines for both high- and low-profit markets. Increasing the cost of making changes did not temper these effects. Adding a cost to making changes seemed like a potential way to encourage decision makers in high feedback frequency environments to think carefully before making changes in order quantities but actually hurt performance among those who received feedback most frequently. A process tracing study helps explain these results by showing that feedback frequency not only changes the amount of information that is processed but also the way in which this information is acquired and processed. In particular, more frequent feedback led decision makers to process information by round rather than across rounds and to be less selective in their processing of feedback information, suggesting more compensatory decision processes (Payne et al., 1988). Although more compensatory decision processes are generally associated with higher quality decisions in traditional choice environments, they seem to have a harmful effect on performance here, where greater attention to random information and a failure to compare information across rounds can hurt performance. Future research, perhaps using verbal protocols, might provide additional insights into how feedback frequency affects information processing. The final study shows that results are driven by feedback, rather than decision, frequency. In other words, whether one makes a single decision for multiple rounds at a time or a different decision for each round, increased feedback frequency hurts performance.

Although we found evidence in some cases for experience-based performance improvements, and differences in these effects across feedback conditions, these were not replicated in all of the studies. Relatedly Schweitzer and Cachon (2000) found no significant experience effects, suggesting that increased experience may not take away the deleterious effects of increased feedback frequency even in straightforward newsvendor settings. More importantly, other settings involving nonstationarity in demand distributions, dynamic and endogenous effects across distribution channel members, and manager turnover may prevent learning from occurring.

Beyond inventory ordering, there are other domains in which feedback frequency may have similar effects. For example, Barber and Odean (2000, 2001) found that investors who trade more frequently, or online, have lower performance. Feedback frequency may be a possible explanation for these results but there are competing explanations. For example, those who trade more often may be more risk-seeking or be overconfident based on an abundance of information or the ease with which trades can be made (Barber & Odean, 2001). Future research could seek to disentangle these alternative explanations.

There are limitations in the extent to which these results are generalizable to other decision settings. Although many decision environments are characterized by random noise, for which more frequent feedback may be harmful, there are other environments in which more frequent feedback may have benign or even helpful effects. In addition to the low-variance environments examined in Experiment 1, in which feedback frequency did not significantly impact performance, these might include settings in which the distribution of demand is unknown—such as for really new products—and settings in which fluctuations in demand represent systematic trends, rather than stochastic noise. Future research could examine the conditions under which more frequent feedback enhances performance.

In addition, although Experiment 2 suggests that raising the costs of making changes increases the detrimental effects of more frequent feedback, we did not provide participants with performance-based incentives. Future research could examine whether the effects of feedback frequency are moderated by performance incentives. Also, in the studies conducted here, cognitive feedback on decisions and realized demand was provided at the same frequency as outcome feedback on performance. Future research could manipulate these independently to examine the relative effects of feedback frequency on cognitive-versus outcome-feedback.

This article suggests that feedback frequency affects performance by changing the processing of feedback information. In the studies presented here, all participants received the same type and amount of overall information, and there was no delay between making (a) decision(s) and receiving feedback specific to that decision(s). In other contexts these may vary. For example, firms may provide decision makers with daily reports of moving averages of monthly demand and performance, thus transforming the feedback information and introducing feedback delay by incorporating information from prior decisions. Relatedly, investment websites often provide frequent, but delayed, stock price information. Future research could examine the relationships among feedback frequency, information aggregation, and feedback delay, perhaps by presenting decision makers with averages and other information summaries. Alternatively, research could examine the effects of educating decision makers on the need to consider more information and temper their responses to noisy information.

Common thinking among practitioners is that real-time information systems are likely to resolve most problems related to uncertainty. Ironically, early research in operations (Forrester, 1958) suggested that managers obtain more reliable demand information by waiting for several weeks in order for short-term variations to be filtered out. It is well established that human interaction with information systems plays an important role in their eventual success (Zuboff, 1982). Our results show that the interactions between the human decision maker and the information system may lead to outcomes counter to what might be expected, particularly in environments with frequent feedback and random noise. This opens up research questions in several dimensions: (1) Will similar results be found in domains such as marketing, healthcare, and finance, where information technology advances are also likely to increase the frequency of feedback to decision makers? (2) How can managers mitigate the potentially harmful impact of feedback frequency on performance? (3) Can decision makers be given incentives to mitigate the effects of more frequent feedback? (4) What is the effect of feedback frequency on learning? These and related questions could be avenues for further exploration by interested researchers.

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