

Specificity Versus Variability: Effects of Practice Conditions on the Use of Afferent Information for Manual Aiming

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Although proponents of the motor schema theory hold that a decrease in the reliance on afferent information will occur with practice in consort with the development of motor programs, supporters of the specificity of practice hypothesis suggest that a performer's reliance on the available sources of afferent information during acquisition increases with the amount of practice. To reconcile these competing positions, four groups of 9 participants aimed to targets under either a constant or a variable practice schedule, with or without vision of the effector. After modest (15 trials) and moderate (150 trials) practice, participants were tested in both their own and in the alternate vision condition. Results indicate that the utilization of online kinesthetic information was enhanced through practice regardless of the availability of vision during acquisition. This was especially true for the groups practicing under a variable practice schedule.

Key Words: manual aiming, afferent information, practice condition

For more than a century, it has been known that visual information is crucial for the performance of accurate movements (Woodworth, 1899). However, the exact nature of the relation between afferent visual information and efferent processes in skilled motor behavior is still highly debated (Elliott, Binsted, & Heath, 1999). Of relevance to the present study is the debate on how the conditions of visual feedback affect motor learning. Although most authors agree that visual information is important for the completion of an accurate movement in the early stages of skill acquisition, there is still no consensus on how the role of vision changes with practice (e.g., Proteau, 1992 vs. Whiting, Savelsbergh, & Pijpers, 1995). This debate underlies an important theoretical construct of motor preparation.

Schmidt (1975) proposed that, as learning progresses, an internal representation for a class of movements develops. The development of this representation, or generalized motor program (GMP), depends on the formation of schema that specify the relation between movement parameters and movement outcomes. As

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skill develops, a single GMP can be used to generate a variety of outcomes through the specification of different parameter values. For example, in tennis, a GMP for a top-spin shot might be selected, and a set of parameters (e.g., force, spatial orientation of the racket) would then determine the specific characteristics of the shot (e.g., speed, direction).

Fundamental to the concept of GMP and the development of motor schema is variability of practice with different parameter values within a class of movements. Only through associating particular parameter values (e.g., units of force) with particular movement outcomes (e.g., movement distance) can motor schema, and thus GMPs, develop. Consistent with Schmidt's (1975) schema theory, a number of researchers have reported that variable practice (i.e., practice with multiple parameter values) facilitates motor learning as compared to constant practice (i.e., practice with a single parameter value; see Shapiro & Schmidt, 1982). From the perspective of the afferent versus efferent debate mentioned earlier, Schmidt's notion of the GMP holds that the need for online afferent control will diminish with practice (see Schmidt & McCabe, 1976). However, this view of a progression in motor learning from closed-loop control to open-loop control, as GMPs are formed over practice, has recently been challenged by Proteau and his colleagues (see Proteau, 1992, for a review).

Proteau's work has concentrated directly on changes in the role of online afferent information with practice. According to the specificity of practice hypothesis, a performer's reliance on the dominant source of response-produced feedback for a given task increases with the amount of practice the performer receives. Modifying the conditions of afferent information from acquisition to transfer has been shown to lead to decrements in performance (Proteau & Cournoyer, 1990; Proteau, Marteniuk, & Lévesque, 1992). Moreover, this disruption of performance has been shown to be greater following extended, as opposed to moderate, practice (Proteau, Marteniuk, Girouard, & Dugas, 1987; Proteau, Tremblay, & DeJaeger, 1998). Thus, at least with respect to the changing importance of afferent information as a function of practice, Proteau's (1992) specificity of learning hypothesis is at theoretical odds with Schmidt's (1975) motor schema theory. However, the empirical work associated with the Schmidt's schema theory and Proteau's specificity of learning hypothesis seems to indicate that creating variability in parameter specification, while maintaining consistency with respect to the sensory circumstance, may be optimal for the acquisition of closed motor skills.

While Schmidt's (1975) theory and Proteau's (1992) hypothesis have received a lot of attention recently, there is another view concerning the use of afferent information over practice. In 1963, Fleishman and Rich proposed that exteroceptive information (i.e., vision) would be used early in practice. However, instead of a reduction (e.g., Schmidt, 1975) or an increase (e.g., Proteau, 1992) in the use of afferent information, Fleishman and Rich (1963) proposed that there would be an increase in the use of interoceptive information (i.e., kinesthetic) as a function of practice. This proposition suggests a progression from the use of visual information to the use of kinesthetic information with practice. Thus, there is a change in the dominant source of afferent information with practice.

In the present experiment, we attempted to gain insight into the influence of parameter variability and afferent specificity in the motor learning process by orthogonally manipulating the two variables. We had four groups of participants learn to perform an aiming movement of defined amplitude with full vision (FV)

or vision of the target only (TO), and under either a variable (VAR) or a constant (CST) practice schedule (i.e., participants practiced under one of four conditions: VAR-FV, VAR-TO, CST-FV, or CST-TO). For the constant practice groups, only one target (i.e., one amplitude) was used, whereas the variable practice group learned to make the aiming movement to five different targets. Following both modest (15 trials) and moderate (150 trials) practice in their own group, each participant completed two tests. One test was performed in the FV condition, and the other was performed in the TO condition. According to the specificity of learning hypothesis (Proteau, 1992), all groups should show a decrease of performance when transferred to the other vision condition (i.e., from FV to TO and from TO to FV). Moreover, this decrease of performance should be larger after 150 trials than after 15 trials. This pattern of results would suggest that the importance of visual information increases as a function of practice (Proteau, 1992). According to motor schema theory (Schmidt, 1975), the variable practice groups should perform better than the constant practice groups in the TO transfer regardless of the vision condition they practiced under. As well, the impact of changing vision condition would be expected to diminish as the number of practice trials under the variable practice schedule increased from 15 to 150. This pattern of results would suggest that the use of visual information decreases as a function of practice.

Method

Participants

Thirty-six undergraduate students in kinesiology at McMaster University participated in this experiment ($M = 19.7$ years old, $SD = 1.4$ years). There were 7 females and 2 males in each group. All participants were right-handed and had normal or corrected-to-normal vision. They were naive to the purpose of the experiment.

Task and Apparatus

Participants were asked to perform an aiming movement with a mouse on a digitizing tablet. The position of the mouse on the tablet was represented on a computer monitor such that 1 mm displacement of the mouse was represented by a 1 mm displacement of the cursor on the mirror. Thus, the cursor virtually represented the participant's hand in the computerized movement environment. The mouse position was sampled at a rate of 138 Hz (one sample every 7.2 ms). The aiming movement was physically constrained by a track guiding the mouse allowing only a linear movement aligned with the sagittal axis of the participant's body. A mirror fixed 15 cm over the digitizing tablet reflected the representation of the home position (3 mm diameter), the target (2 mm diameter), and the moving cursor (2 mm diameter) from a computer monitor that was located 35 cm above (see Figure 1A). This experimental setup allowed for the manipulation of the vision of the cursor. In order to increase the difficulty of the task, the monitor was rotated 180° such that the direction of the movement of the cursor was opposite to the direction of the limb. Thus, while the "real" home position was close to the participant on the digitizing tablet, its "virtual" representation on the mirror was away from the participant and vice versa for the targets (see Figure 1B). This manipulation was done to favor learning and prevent early ceiling effects usually found when acquiring simple tasks. In the constant practice condition, the target was

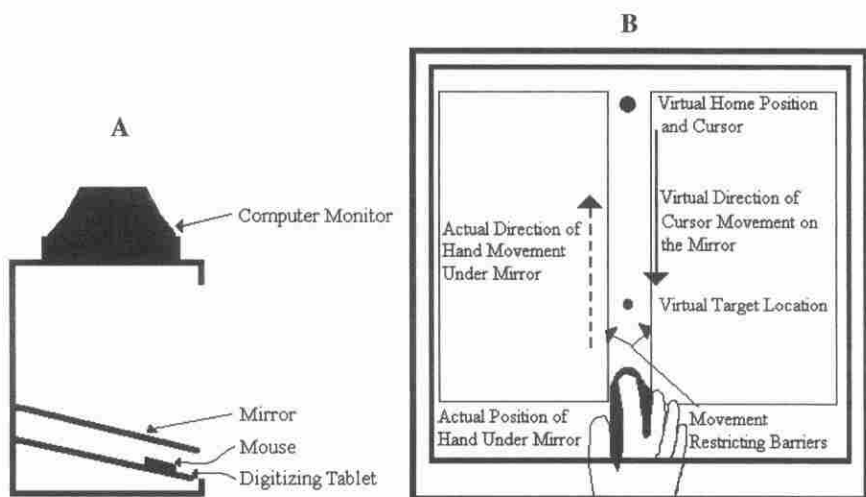


Figure 1 — Picture of the apparatus (A) and description of the limb-cursor representation (B).

always 14 cm from the home position. In the variable condition, the target was either at 9 cm, 11.5 cm, 14 cm, 16.5 cm, or 19 cm from the home position. The presentation of the different targets in the variable condition was randomized in such a way that each target was presented once every five trials.

Procedures

Each participant was randomly assigned to one of the four groups (i.e., VAR-FV, VAR-TO, CST-FV, or CST-TO), with the constraint that groups were balanced for gender. Although conditions of practice varied for each group, each participant went through the same schedule of practice and testing. After an explanation of the protocol and a brief orientation to the task, the experimental session began with the first acquisition phase that consisted of 15 trials under the conditions of practice designated for each group. Following the first acquisition phase, participants completed two test phases that consisted of movements to the 14-cm target only. The first test phase consisted of 10 movements made in the same vision condition in which they had just practiced (i.e., FV to FV, TO to TO). In the second transfer phase, participants performed 10 more aiming movements in the other vision condition (i.e., FV to TO, TO to FV). Following these test phases, participants completed another 150 acquisition trials in the same condition as their first acquisition phase. A 5- to 10-min pause was taken after the fourth, fifth, or sixth block of 15 trials of the second acquisition phase in an attempt to stave off boredom or fatigue effects. Finally, at the end of the second acquisition phase, participants had to complete two more transfer tests in the same order as the first test session.

A typical trial started with the appearance of the cursor on the mirror. The participant was instructed, upon the appearance of the cursor, to move the mouse on the digitizing tablet such that the cursor was inside the home position. One second after the cursor appeared, the target illuminated. Participants were informed

that reaction time was not critical in this task; rather, the purpose was to accurately place the cursor on the target within a movement time bandwidth (360–440 ms). This movement time was sufficiently large for online visual feedback utilization (see Carlton, 1992, for a review). After each movement in the acquisition phase, KR was provided about movement time and accuracy/bias. More specifically, movement time KR was given on the screen in milliseconds. The experimenter verbally pointed out when movement time was outside the prescribed bandwidth. The spatial KR involved simultaneous presentation of the target position and the final position of the cursor. Thus, the participant was aware of both the magnitude and the bias (i.e., overshoot or undershoot) of the spatial error. In the transfer phases, however, only movement time KR was provided.

Dependent Variables

Displacement profiles were initially filtered using a dual-pass Butterworth filter with a low cut-off frequency of 10 Hz. These filtered displacement profiles were then differentiated to create velocity profiles. Both performance- and kinematic-dependent variables were derived from these profiles using custom software (Chua & Elliott, 1993). The start and the end of the movement were identified as the frame at which the velocity of the movement rose above or fell below 30 mm/s, respectively, and remained there for 50 ms (7 frames). Movement time (MT) was calculated by multiplying the number of frames between the start and end of the movement by 7.2 ms/frame. The other performance variables were constant error (CE) and variable error (VE). These two variables provide information about average movement accuracy/bias and consistency, respectively (Schmidt & Lee, 1999). We also examined peak velocity (PV), time after peak velocity (TAPV), and proportional time to peak velocity (PTPV) based on the assumption that changes in these kinematic variables would reflect adjustments of programming and online feedback utilization (e.g., Elliott et al., 1999).

Data Analyses

Each dependent variable was separately contrasted with a mixed analysis of variance (ANOVA) comparing 2 Vision Group (FV, TO) $\times$ 2 Practice Schedule (VAR, CST) $\times$ 2 Test Condition (FV, TO) $\times$ 2 Test Time (15, 150). For significant effects involving more than two means, Tukey *HSD* post hoc analyses ($p < .05$) were conducted. Inferential statistics for these main analyses are presented in Table 1.

Results

Performance

The movement time analyses revealed main effects for Test Time and Test Condition. It was not surprising to observe shorter movement times after 150 trials than after 15 trials and shorter movement times in the TO than in the FV condition. Although participants performed within the prescribed movement time bandwidth, a Test Time by Test Condition interaction revealed that participants took more time to complete their response in the FV test than in the TO test after 15 trials only (see Table 2). Further, a Practice Schedule by Test Condition interaction

Table 1 *F* ratios (1, 32) for Each Statistical Test of All Dependent Variables

Variable	Dependent variable					
	MT	CE	VE	PV	TAPV	PTPV
Vision group (VG)	0.16	4.09	0.75	0.88	3.54	2.87
Practice schedule (PS)	3.60	3.84	0.06	0.92	0.02	0.15
Test time (TT)	21.01**	12.46**	27.56**	0.84	62.61**	10.36**
Test condition (TC)	8.85**	30.21**	11.45**	17.36**	50.32**	66.03**
VG × PS	0.90	0.02	0.61	0.74	9.72**	8.03**
VG × TT	0.66	1.60	0.72	0.00	0.17	0.60
PS × TT	0.96	1.17	0.98	0.94	0.85	0.91
VG × TC	1.27	1.34	7.02*	2.48	0.12	0.80
PS × TC	12.25**	4.34*	1.06	1.21	8.18**	6.95*
TT × TC	5.54*	8.74**	8.52**	9.34**	24.92**	33.82**
VG × PS × TT	0.06	0.00	1.96	0.17	14.41**	23.79**
VG × PS × TC	0.13	0.16	0.81	3.53	15.53**	3.89
VG × TT × TC	0.49	1.08	0.01	0.85	0.13	0.01
PS × TT × TC	2.57	0.94	0.06	1.84	0.04	0.00
VG × PS × TT × TC	0.05	0.32	0.19	3.20	0.81	0.36

* $p < .05$; ** $p < .01$.**Table 2** Mean Movement Time in Milliseconds (*SD*) as a Function of Vision Group, Practice Schedule, Test Time, and Test Condition

Variable	After 15 trials		After 150 trials	
	TO	FV	TO	FV
VAR-FV	382 (29)	421 (44)	354 (13)	370 (27)
CST-FV	385 (27)	376 (20)	366 (20)	355 (19)
VAR-TO	395 (19)	448 (29)	365 (10)	382 (13)
CST-TO	378 (21)	387 (69)	346 (17)	346 (25)

revealed that only participants from the variable practice schedule groups were slower in the TO tests than in the FV tests (see Table 2).

The CE analysis revealed main effects for Test Time and Test Condition as well as a Practice Schedule by Test Condition interaction and a Test Time by Test Condition interaction. Overall, participants were more accurate after 150 trials than after 15 trials of practice, although they generally overshot the target. Not surprisingly, participants were more accurate in the FV test than in the TO test. Post hoc analysis of the Practice Schedule by Test Condition interaction revealed an interesting result. As depicted in Figure 2A, while participants from the variable

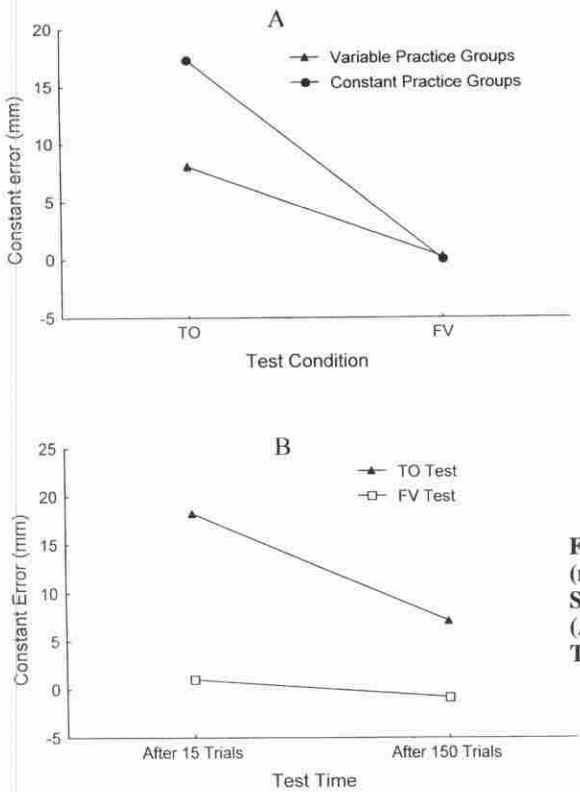


Figure 2 — Constant error (mm) as a function of Practice Schedule and Test Condition (A) and as a function of Test Time and Test Condition (B).

Table 3 Variable Error in Millimeters (SD) as a function of Vision Group, Practice Schedule, Test Time, and Test Condition

Variable	After 15 trials		After 150 trials	
	TO	FV	TO	FV
VAR-FV	15 (7)	8 (2)	10 (5)	9 (2)
CST-FV	16 (7)	11 (4)	10 (3)	8 (2)
VAR-TO	15 (6)	11 (3)	10 (3)	10 (2)
CST-TO	13 (4)	12 (3)	9 (4)	12 (5)

practice groups were not significantly affected by the vision manipulation, participants in the constant practice groups were less accurate when vision of the cursor was not permitted. This finding could support the idea that either: (a) variable practice enhanced motor programming abilities; or (b) variable practice enhanced efficient use of kinesthetic feedback. In either case, the results suggest that a performer is less reliant on visual information after variable practice than after constant practice. Further, post hoc analysis of the Test Time by Test Condition

interaction revealed that the effect of vision withdrawal was detrimental to performance after 15 trials but not after 150 trials of practice (see Figure 2B). This result is opposite to predictions of the original version of the specificity of practice hypothesis (Proteau, 1992). However, separate analyses of both groups who practiced in full vision revealed a significant interaction of Test Time by Test Condition for the VAR-FV group, $F_{1,32} = 7.65$, $p < .01$, but not for the CST-FV, $F_{1,32} = 1.51$, $p > .2$. Thus, compared to constant practice, only variable practice allowed participants to be less dependent on vision after more practice.

The VE results revealed main effects for Test Time and Test Condition as well as a Vision Group by Test Condition interaction and a Test Time by Test Condition interaction. As one would expect, participants were less variable after 150 trials of practice than after 15 trials of practice, and they were less variable in the FV tests than in the TO tests (see Table 3). Also, while it was found that the groups practicing in full vision showed greater variability in the TO condition than in the FV condition, the groups practicing in the target only condition showed similar variability in both transfer tests (see Figure 3A). This VE result is consistent with the specificity of practice hypothesis (Proteau, 1992). Conversely, as it was found in the CE results, participants were more variable in the TO condition than in the FV condition only after 15 trials of practice (see Figure 3B). However, unlike the CE results, the separate analyses for each FV group did not reveal that the variable practice schedule accounted for the lack of specificity with the VE. Overall, for both CE and VE results, it appears that participants were less affected by vision withdrawal after 150 acquisition trials than after 15 trials.

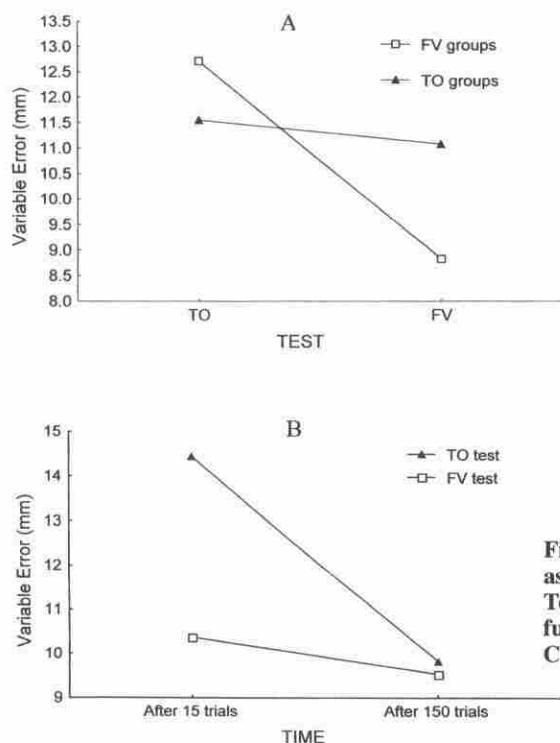


Figure 3 — Variable error (mm) as a function of Vision Group and Test Condition (A) and as a function of Test Time and Test Condition (B).

Kinematics

The PV analysis yielded a main effect for Test Condition and a Test Time by Test Condition interaction. Post hoc analysis of the interaction revealed participants achieved greater maximal velocity in the FV test after 150 acquisition trials than after 15 trials. No effect of practice was found in the TO test. Accordingly, after 15 acquisition trials, participants achieved higher peak velocity in the TO than in the FV test, whereas their average peak velocity was similar in both transfer tests after 150 acquisition trials (see Figure 4).

The TAPV analysis revealed main effects for Test Time and Test Condition, as well as a Test Time by Test Condition interaction. Post hoc analysis of this interaction revealed that participants spent less time after peak velocity after 150 practice trials than after 15 practice trials in the FV tests only. There was also a Vision Condition by Practice Schedule interaction, a Vision Condition by Practice Schedule by Test Condition interaction, and a Vision Condition by Practice Schedule by Test Time interaction. Post hoc analysis of these interactions revealed that only the VAR-FV group took more time after peak velocity in the FV than in the TO tests (see Table 4). Further, only the VAR-FV and the CST-TO groups showed a decrease of time after peak velocity between the transfer tests performed after 15 acquisition trials to the tests performed after 150 trials (see Table 4). Finally, there

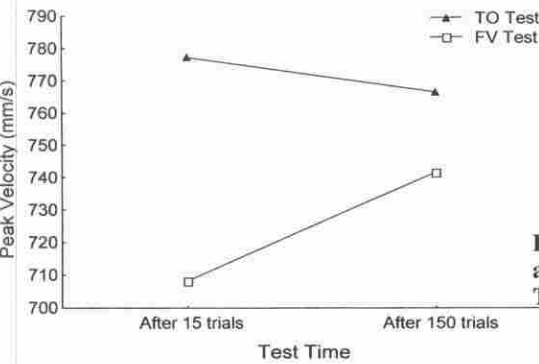


Figure 4 — Peak velocity (mm/s) as a function of Test Time and Test Condition.

Table 4 Average Time After Peak Velocity in Milliseconds (SD) as a Function of Vision Group, Practice Schedule, Test Time, and Test Condition

Variable	After 15 trials		After 150 trials	
	TO	FV	TO	FV
VAR-FV	214 (27)	270 (41)	194 (12)	217 (27)
CST-FV	205 (20)	217 (19)	207 (19)	199 (23)
VAR-TO	189 (15)	218 (36)	186 (9)	189 (16)
CST-TO	211 (13)	250 (19)	195 (8)	200 (14)

Table 5 Average Proportional Time to Peak Velocity in Percent (*SD*) as a Function of Vision Group, Practice Schedule, Test Time, and Test Condition

Variable	After 15 trials		After 150 trials	
	TO	FV	TO	FV
VAR-FV	44 (4)	36 (3)	45 (2)	42 (3)
CST-FV	47 (3)	42 (3)	43 (3)	44 (3)
VAR-TO	50 (2)	44 (3)	46 (1)	45 (2)
CST-TO	43 (3)	38 (3)	46 (3)	45 (2)

was a Practice Schedule by Test Condition interaction, but post hoc analyses revealed that both variable practice groups and constant practice groups spent more time after peak velocity in the FV than in the TO tests.

For the PTPV results, there was a main effect for Test Time, Test Condition, and a Test Time by Test Condition interaction. The post hoc analysis of this interaction revealed a greater proportion of time to peak velocity in the TO test than in the FV test after 15 acquisition trials but not after 150 trials (see Table 5). In other words, practice led the participants to increase the proportion of time taken before peak velocity in the FV test only. There was also a Vision Condition by Practice Schedule interaction and a Vision Condition by Practice Schedule by Test Time interaction. Post hoc analysis of the three-way interaction revealed that the CST-TO group showed an increased PTPV from the transfer tests performed after 15 acquisition trials to the tests performed after 150 trials (see Table 5). The VAR-FV group showed a non-significant trend for a similar effect ($p = .057$). Interestingly, the PTPV mean for each group in each transfer test never reached more than 0.50, indicating that the greater part of the movement was usually spent in the deceleration (i.e., corrective) phase of the movement (Elliott et al., 1999; see also Woodworth, 1899).

Discussion

The purpose of the present study was to combine the paradigms traditionally employed to investigate the motor schema theory and the specificity of practice hypothesis, and critically appraise the results with reference to these theories. The most relevant finding was that spatial error decreased as practice increased even when visual information available during acquisition was eliminated. This result is opposite to what is predicted by the early version of the specificity of practice hypothesis (Proteau, 1992). To our knowledge, this is the first time such a pattern has emerged in a manual aiming study. This result could either indicate a reduction in the use of afferent information as a function of practice (e.g., Pew, 1966; Schmidt & McCabe, 1976) or that practice allows the learner to make greater use of kinaesthetic information (e.g., Fleishman & Rich, 1963). However, before evaluating these hypotheses through an examination of both kinematic and performance data, it was necessary to determine if the absence of specificity effects could be attributed to the nature of the task.

Initially, it was suspected that the reversed mapping between the direction of the limb and the resulting displacement of the cursor could have caused these unique results. Such a limb-cursor mapping has not been used to investigate the specificity of practice thus far, and the unusual results could be due to a disruption of the normal relationship between limb movement and response-produced feedback. To determine if this was the case, a fifth group of participants ($n = 9$) were recruited to complete the same protocol as the CST-FV group except that the computer monitor was re-oriented. As a result, this group had direct mapping between the direction of the cursor and the limb (i.e., both moving in the same direction). Separate ANOVAs were performed for CE and VE, contrasting 2 Mapping Condition (Inverted, Direct) $\times$ 2 Test Condition (FV, TO) $\times$ 2 Test Time (15, 150). This analysis did not reveal any significant main effect or interaction involving the mapping condition.¹ Therefore, the relative direction of the cursor and the limb could not account for the performance results found in the main analysis. There are, however, two other methodological differences between previous research on the specificity of practice hypothesis and the present study.

First, while most studies supporting the specificity of practice hypothesis employed a movement that involved at least two degrees of freedom (cf. Adams, Gopher, & Lintern, 1977), the task utilized in the present study involved only one degree of freedom. Controlling only movement amplitude might differ from controlling two or three dimensions. Indeed, there is evidence to suggest the existence of distinct systems for the control of movement amplitude and movement direction (Ghez, Gordon, Ghilardi, & Sainburg, 1994; Smyrnis, Evdokimidis, Constantinidis, & Kastrinakis, 2000). Second, the amplitude of the movement in the present study was relatively small. For example, Proteau et al. (1987) used a 90-cm movement, while we used a 14-cm movement. It might be possible that the movement involved in the present study led to the observed results. Thus, practicing short amplitude movements or solely controlling movement amplitude might lead to a reduction in the need for online afferent information or the eventual dominance of online kinesthetic information. To resolve this issue, we examined how the performance and the kinematic results covary.

On one hand, the spatial accuracy/consistency results (i.e., CE and VE) reflected a reduction in the importance of visual information as a function of practice. As mentioned earlier, this could support either of the two remaining theoretical views (i.e., Schmidt & McCabe, 1976 vs. Fleishman & Rich, 1963). At first glance, the kinematic results appear to support Schmidt and McCabe (1976) and Pew (1966). Specifically, participants reduced their opportunity to utilize online feedback as a function of practice by taking less time to decelerate their limb movement (TAPV). However, peak velocity also increased with practice. This brings the limb closer to the target earlier in the movement, creating the opportunity for earlier detection and correction of movement error (Elliott, Helsen, & Chua, 2001). Given that after 150 trials of practice participants still spent more time decelerating than accelerating their limb (PTPV < 0.5), they still had plenty of time

¹For CE, participants were more accurate in the full vision condition (0.1 mm) than in the target only condition (17.3 mm), $F_{1,16} = 30.49$, $p < .001$. For VE, participants were less variable after 150 trials of practice (8.6 mm) than after 15 trials (11.9 mm), $F_{1,16} = 23.00$, $p < .001$, and they were less variable in the FV tests (8.2 mm) than in the TO tests (12.2 mm), $F_{1,16} = 23.79$, $p < .001$.

(TAPV > 180 ms) to utilize online afferent information (see Carlton, 1992, and McCloskey, 1978, for reviews of visual and kinesthetic processing times). Therefore, the pattern of results for the kinematic data may indicate that participants increased their efficiency at utilizing online feedback as a function of practice (Elliott, Chua, Pollock, & Lyons, 1995; Elliott & Lyons, 1995; Proteau, 1992) rather than decreased their use of online afferent information with practice (Pew, 1966; Schmidt & McCabe, 1976). This evidence for online afferent information processing does not mean that participants did not also improve at specifying the initial motor commands. As Khan, Franks, and Goodman (1998) have demonstrated, improved programming and online control are not mutually exclusive. Nevertheless, in the present study, practicing under the present FV and the TO conditions led to a more efficient use of online kinesthetic information.

A more recent view of the specificity of practice phenomenon is consistent with the present work. Tremblay and Proteau (1998) proposed that, as one practices a task, a single source of online afferent information is likely to dominate other sources. Perhaps for the short amplitude aiming movements of this study (i.e., less than 15 cm), the use of online kinesthetic information dominates over vision and, as such, its importance increases with practice. Alternatively, it might be that kinesthetic information is more important for amplitude control, while vision dominates for the control of movement direction (see Ghez et al., 1994). Consistent with these ideas is that visual occlusion was less detrimental to performance after more practice (i.e., after 150 trials vs. after 15 trials). Considering that kinesthesia could dominate over vision when it is present, our conclusions actually reconcile Proteau's (1992) and Fleishman and Rich's (1963) view. Moreover, such dominance can also be affected by the practice schedule.

It has been proposed that variability of practice enhances movement parametrization and planning (Schmidt, 1975). However, the VAR-FV group, which showed a smaller performance decrement following visual occlusion of the limb after 150 acquisition trials than after 15 trials, also displayed movement profiles consistent with the use of online kinesthetic feedback. Thus, all groups were probably using online afferent information (i.e., kinesthetic) to achieve the correct movement amplitude after extended practice. Further, it appears that the variable practice groups were able to use this source of afferent information more efficiently after greater practice than the constant practice groups. This proposition is supported by the additional analyses that compared the CST-FV group to the additional group who had direct mapping. Indeed, in these separate analyses, the Test Time by Test Condition interactions fell short of significance (CE: $F_{1,16} = 1.86$, $p = .19$; VE: $F_{1,16} = 3.27$, $p = .09$). This indicates that, regardless of limb-cursor mapping, the constant practice schedule did not lead participants to make better use of online kinesthetic information. As a result, the present study reveals that a variable practice schedule can also enhance online feedback utilization (i.e., error detection and error correction) instead of solely enhancing motor parametrization. Of course, this proposition needs to be directly examined in a study that includes the manipulation of multiple sources of afferent information including kinesthetic feedback. Further, other types of movement of greater amplitude involving more than one degree of freedom should be investigated.

As an addendum, we conclude with some methodological considerations for future research on the specificity of practice hypothesis. First, future work on the use of afferent information should manipulate the availability of more than one

source of feedback (see Coull, Tremblay, & Elliott, in press). From a theoretical standpoint, conclusions about the use of kinesthesia require its direct manipulation, as most practice conditions involve a multi-sensory environment. Second, investigations into the use of afferent information should also manipulate practice schedule because it appears to be critical in mediating motor learning. From a practical point of view, practice structure is much easier for an instructor to control than the afferent information available during skill acquisition.

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