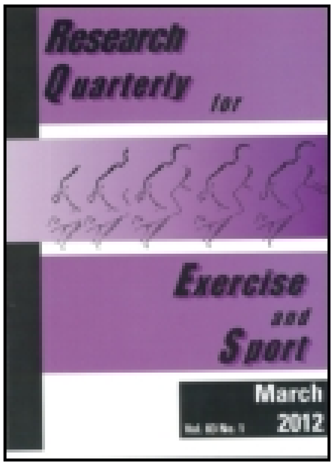

Research Quarterly for Exercise and Sport
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/urqe20

The Amount of Practice Really Matters

Olav E. Krigolson [a] & Luc Tremblay [b]
[a] Department of Psychology , University of British Columbia
[b] Faculty of Physical Education , Health at the University of Toronto
Published online: 23 Jan 2013.

Research Quarterly for Exercise and Sport

Vol. 80, No. 2, pp. 197–204

The Amount of Practice Really Matters: Specificity of Practice May Be Valid Only After Sufficient Practice

Olav E. Krigolson and Luc Tremblay

Studies investigating the specificity hypothesis have not always demonstrated that reliance on a specific source of feedback increases with practice. The goal of the present study was to address this inconsistency by having participants practice a throwing task with or without vision at incremental levels (10, 50, 100, or 200 acquisition trials). Following acquisition, all participants in the present experiment performed 10 trials in a no-vision transfer condition. Our results demonstrated that, given a sufficient number of acquisition trials, feedback reliance increased as a function of time engaged in practice. Our results also suggest that increased reliance on a specific source of feedback occurs only after the control strategy for a task is optimized.

Key words: motor learning, motor schema, visual feedback

The precise role of feedback during skill acquisition is still unclear. On one hand, it makes sense that practice would enable the development of a precise internal representation of the task that would reduce the reliance on sensory feedback (i.e., open-loop theories). One open-loop theory (i.e., motor schema theory; Schmidt, 1975) proposes that while feedback is important in the early stages of skill acquisition, the need for feedback is reduced with practice as performers acquire a *schema* for the skill. In other words, with practice, performers gradually shift from a closed-loop (i.e., with feedback) to an open-loop mode of control (i.e., without feedback). Work by Pew (1966) has been interpreted as support for this. In Pew's research, participants attempted to keep a cursor on a cathode ray tube aligned with a moving target via discrete key presses. Pew found that over fifteen 1-hr sessions of practice (distributed over 15 weeks) the time interval between key presses decreased from 458 ms to 292 ms. This result prompted Pew to suggest that performers shifted from a closed to open-loop mode of control during the experiment. However, as noted by Proteau, Tremblay, and DeJaeger (1998), a control condition in Pew's experiment, where participants rapidly alternated pressing the left and right keys without consideration for the alignment of the cursor with the target, yielded a much shorter interresponse interval (125 ms). With this in mind, an alternate interpretation of Pew's results suggests that while the amount of time required for an accurate response decreased with practice, the control process was not entirely open-loop in nature. Indeed, participants may still have been using feedback to achieve movement accuracy, and therefore a shift to an open-loop mode of control may not have occurred in Pew's study (Abrams & Pratt, 1993; Carlton, 1992; Proteau, 1992).

An alternative account of the role of feedback during skill acquisition is provided by the specificity-of-practice hypothesis (Proteau, 1992), which states that, during skill acquisition, performers acquire a skill representation that relies on a specific source of internal feedback. Furthermore, the specificity hypothesis predicts that reliance on a specific source of feedback will increase with practice,

Submitted: March 22, 2006
Accepted: May 23, 2008

Olav E. Krigolson is with the Department of Psychology at the University of British Columbia. Luc Tremblay is with the Faculty of Physical Education and Health at the University of Toronto.

a prediction in direct opposition to Schmidt's schema theory. Moreover, the specificity hypothesis does not rule out the possibility that there is some underlying central movement structure to a motor skill; however, it does emphasize that, for accurate movement production to occur, performers will use an optimal source of internal feedback during movement execution.

The specificity-of-practice hypothesis stemmed from the original work of Proteau, Marteniuk, Girouard and Dugas (1987) investigating the interaction of practice length and visual feedback availability on manual-aiming accuracy. In their experiment, participants practiced reaching to a target in either a full-vision condition, in which the target and hand were always visible, or in a target-only condition, in which only the target was visible. Practice duration was also manipulated so that participants performed reaches in one of the visual conditions for either a brief (200 trials over 1 day) or extended (2,000 trials over 5 days) amount of practice. Following acquisition, all participants were tested in the target-only condition. The results demonstrated that participants in the full-vision practice groups were significantly less accurate than those in the target-only groups in the transfer condition. Furthermore, the results indicated that participants who underwent 2,000 full-vision trials during acquisition were significantly less accurate than participants who performed 200 full-vision trials during acquisition. These results implied that participants became reliant on a specific source of internal feedback during skill acquisition. These results also indicated that feedback reliance increased as a function of practice during skill acquisition, given that the 2,000 trial full-vision group was less accurate than the 200 trial full-vision group in the transfer condition.

Since Proteau et al.'s (1987) original study, the specificity-of-practice hypothesis has been supported by a variety of manual-aiming study designs (Proteau, 1995; Proteau & Cournoyer, 1990; Proteau & Isabelle, 2002; Proteau & Marteniuk, 1993) and gross motor tasks (Krigolson, Van Gyn, Tremblay, & Heath, 2006; Proteau et al., 1998; Tremblay & Proteau, 1998). However, support for the specificity hypothesis has been limited because some studies have failed to produce results predicted by the specificity hypothesis (i.e., Bennett & Davids, 1995a, 1995b; Robertson, Collins, Elliott, & Starkes, 1994; Whiting, Savelsbergh, & Pijpers, 1995). A primary criticism collectively raised by these studies is that the specificity hypothesis cannot account for equivalent transfer findings among groups that experienced different amounts of practice with or without vision.

For example, a study by Tremblay and Proteau (1998) failed to demonstrate an increase in the reliance on a specific source of feedback during skill acquisition. Despite significant effects of feedback withdrawal on accuracy, when going from an enhanced full-vision (i.e., aided with a laser beam) acquisition condition to a no-vision transfer, participants demonstrated similar levels of error in a transfer condition regardless of the length of time spent in skill acquisition. While the specificity literature seems to support the position that performers become reliant upon a specific source of feedback with practice, it remains unclear whether this reliance *increases* as a function of practice. In other words, although reliance on feedback does not seem to decrease as a function of practice, it does not always increase either.

The goal of the present research was to clarify this issue: does reliance on a specific source of feedback increase as a function of practice or does it follow a nonlinear pattern? One of the drawbacks of previous studies investigating the specificity hypothesis is that, in most cases, participants engaged in either a brief or extended amount of practice during skill acquisition. Therefore, one can observe decreasing, stable, or increasing reliance on sensory information as a function of practice when using only two amounts of practice.[1] In the present study, we had participants practice a throwing task in either a full-vision or no-vision practice condition for 10, 50, 100, or 200 trials during skill acquisition. Following this, all participants performed 10 transfer trials in a no-vision condition. Typically the specificity hypothesis is tested in this manner: two (or more) groups of participants practice a task, one group with visual feedback and the other without. Following the practice phase, participants in both groups perform a "transfer" test in the no-feedback condition (e.g., Proteau et al., 1998). This manipulation allows a comparison between participants who experience similar internal feedback availability between acquisition and transfer and participants who do not. When visual feedback is being examined, the experimental manipulation usually involves the removal of visual feedback, because adding visual feedback in a transfer condition is thought to provide a means for enhanced online control that may negate an existing reliance upon kinesthetic feedback (c.f., Proteau, Marteniuk, & Lévesque, 1992).

In line with the specificity hypothesis, we predicted that no-vision participants would be more accurate (reduced absolute constant error) and more consistent (reduced variable error) than full-vision participants in the transfer condition. Given previous results, which demonstrated that feedback reliance did not increase as a function of practice (i.e, Tremblay & Proteau, 1998), we predicted the relationship between practice length and visual condition would be nonlinear. Specifically, we hypothesized that for no-vision participants absolute constant error and variable error in the transfer condition would decrease as a function of the number of trials during the acquisition phase. For full-vision participants, we predicted that absolute constant error and variable error in the transfer condition would increase only after a certain amount of practice (100 to 200 trials). Nevertheless, we expected that the specificity hypothesis would be valid after a sufficient amount of practice and therefore predicted that participants, after extended practice, would acquire a sensory-specific movement pattern for the throwing task (i.e., participants who experienced 200 trials of full-vision practice would demonstrate greater absolute constant error and /or variable error scores in the transfer condition relative to participants with less practice in the full-vision practice condition).

Method

Participants

Eight groups of 10 participants (18–26 years old) participated in this experiment. All had normal or corrected-to-normal vision. All participants provided informed consent in accordance with human subjects guidelines established by the University of Victoria.

Task and Apparatus

We chose a throwing task in the present experiment because it provided a novel opportunity to assess whether a ballistic movement (which would not typically be thought to depend on visual feedback) would be susceptible to the specificity hypothesis. A large body of evidence suggests that rapid, ballistic, manual-aiming movement relies on visual feedback to achieve accuracy, and that this feedback can be processed in as little as 100 ms (Desmurget & Grafton, 2000; Elliott & Allard, 1985; Goodale, Pelisson, & Prablanc, 1986; Saunders & Knill, 2003; Yoshida, Cauraugh, & Chow, 2004; Zelaznik, Hawkins, & Kisselburgh, 1983).[2] Research examining open-loop gross motor tasks also suggests that visual feedback during movement execution facilitates accuracy (basketball jump shooting: Oudejans, van de Langenberg, & Hutter, 2002; discus throwing: Lenoir, 2005).

The experiment was conducted in a 20-m x 10-m testing room with 6-m high ceilings. Participants were asked to throw a beanbag 3 m to a marked target location on the floor. The target location consisted of a 1-m line perpendicular to the participants. A series of lines parallel to the target line were faintly marked at 5-cm intervals in both directions to facilitate data collection (see Figure 1). For each experimental trial, the distance between the beanbag and the target line was recorded in the primary throwing axis (i.e., signed amplitude error). Following the end of data collection, these data were converted to absolute constant error scores. Also following data collection, variable error was calculated for each participant for each condition (see below). Participants were instructed to use an underarm-throwing technique, with each trial starting from a checked position with the throwing arm at the side of the body. During no-vision trials, participants wore a pair of blacked-out swimming goggles to occlude vision.

Procedure

Eighty participants completed 10, 50, 100, or 200 acquisition trials in either a full-vision (FV) or no-vision (NV) condition, resulting in eight experimental groups ($n = 10$): FV10, FV50, FV100, FV200, NV10, NV50, NV100, and NV200. Participants assigned to FV groups practiced the throwing task under normal visual conditions. Participants assigned to NV groups practiced the throwing task while wearing the blacked-out goggles; however, participants had vision of the target before and after each trial. In other words, NV participants viewed the target, lowered their goggles, made their throw, and then raised their goggles for each acquisition trial. Consequently NV participants had knowledge of their results after each acquisition trial.

Immediately following the last acquisition trial, participants in all groups performed a transfer test that consisted of 10 NV trials. The NV transfer trials differed slightly from the NV acquisition trials as vision of the target was allowed only before each transfer throw. Following each transfer trial, the experimenter recorded spatial accuracy and returned the beanbag to the participant to remove any performance feedback from the transfer condition. Dependent variables used in this study included absolute constant error and variable error in the primary movement direction (i.e., the main axis of the throwing movement).

Results

To ensure that all of the practice groups started at a similar level of performance, within each visual condition we submitted the absolute constant error associated with the first acquisition block (i.e., the first 10 trials) to

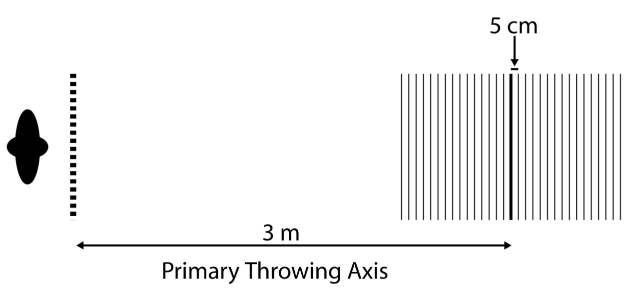

Figure 1. Diagram of the experimental setup. Note that the scoring lines were marked faintly on the floor so as to not be visible to participants.

an analysis of variance (ANOVA). These analyses did not indicate a difference in absolute constant error during the first block of acquisition for either FV participants, $F(3, 36) = 1.59$, $p > .05$, partial $\eta^2 = .12$, or NV participants, $F(3, 36) = 1.58$, $p > .05$, partial $\eta^2 = .12$.

Acquisition Results

We conducted trend analyses to determine whether participants in the 10, 50, 100, and 200 acquisition trial conditions improved their accuracy (absolute constant error) or consistency (variable error) as a function of practice. The results of the trend analyses for absolute constant error indicated that none of the practice groups significantly improved their accuracy during the acquisition phase of the experiment (see Table 1).[3] However, performance improvement in terms of consistency was observed as a reduction in variable error as a function of practice for the FV50, NV50, FV100, NV100, FV200, NV200 practice groups. Variable error was not reduced with practice for the FV10 and NV10 groups (see Table 1 and Figure 2 for more detail). In other words, our results indicated that, for participants with more than 10 acquisition trials of practice, endpoint variability was significantly reduced with practice.

Transfer Results

Data collected in the transfer test for each dependent variable were subjected to a 2 Practice Condition (FV, NV) x 4 Practice Length (10, 50, 100, 200) between-participants ANOVA. Post hoc comparisons were made for significant main effects and interactions using Tukey's HSD method. The analysis of absolute constant error in the transfer condition revealed a significant main effect for practice length, $F(3, 72) = 3.10$, $p < .05$, partial $\eta^2 = .11$. Post hoc analysis of this main effect using Tukey's HSD method failed to yield a significant difference for absolute constant error relating to practice length (see Figure 3, top panel).

Analysis of variable error yielded an interaction between practice condition and practice length, $F(3, 72) =$

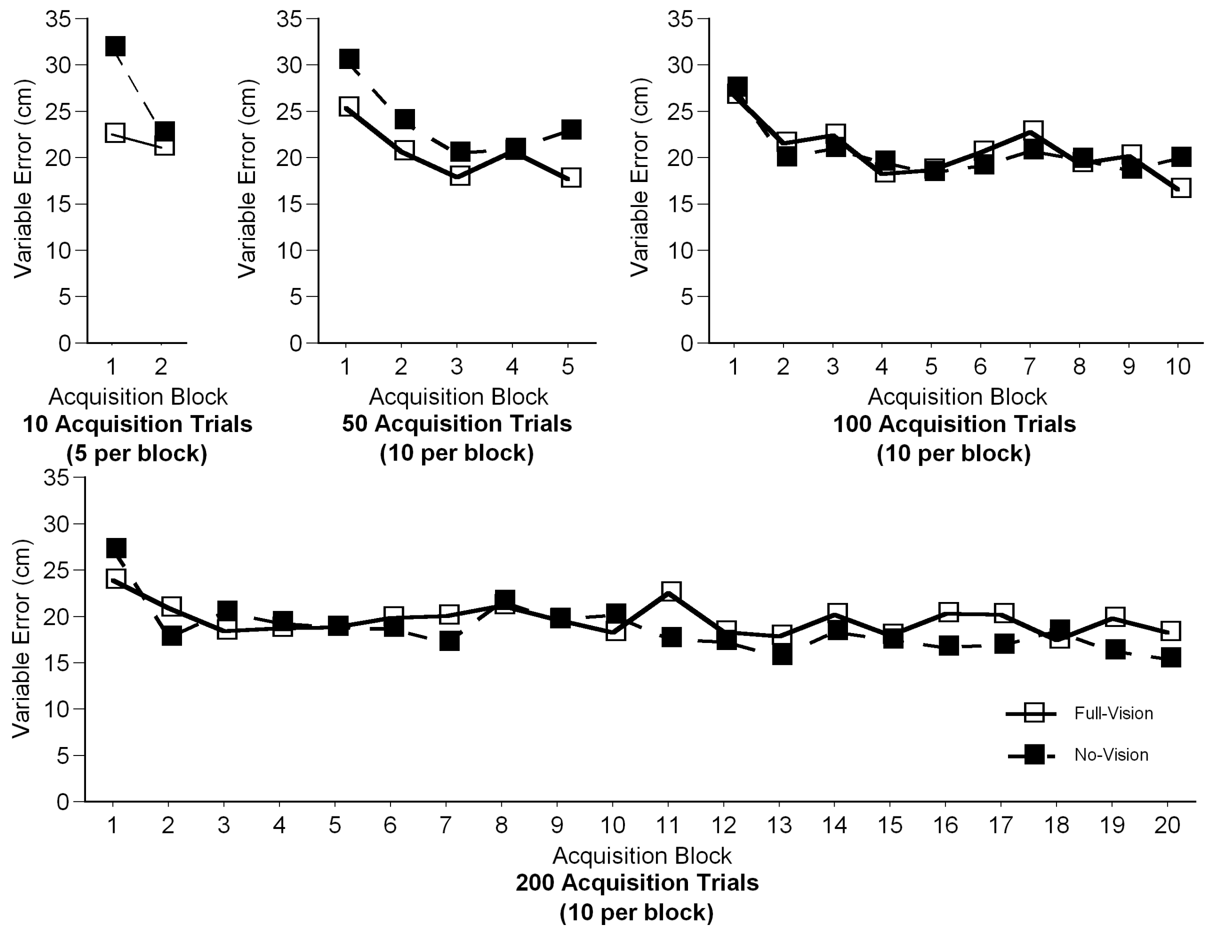

Figure 2. Acquisition variable error (cm) as a function of visual condition and practice block for 10 acquisition trial participants (top left), 50 participants (top middle), 100 participants (top right), and 200 participants (bottom).

5.19, $p < .01$, partial $\eta^2 = .18$. Post hoc analysis of this interaction revealed that the FV10 and FV200 practice groups exhibited greater variable error scores than the FV50 and FV 100 practice groups ($p < .05$) in the transfer condition. Furthermore, the FV10 and FV200 practice groups and the FV50 and FV 100 practice groups did not differ from each other in terms of variable error ($p < .05$). For the NV practice groups, variable error in the transfer condition decreased as a function of practice (see Figure 3 bottom panel for more detail). Specifically, we found that in the transfer condition the NV10 and NV50 practice groups exhibited greater variable error scores than the NV100 practice group, which in turn had a greater variable error score than the NV200 practice group ($p < .05$).

Discussion

Previous studies investigating the specificity-of-practice hypothesis have not always been able to demonstrate that reliance on a specific source of feedback increased with practice (i.e. Proteau et al., 1987, 1998). We speculated that one explanation for the discrepancy in previous findings may be that participants had not been exposed to sufficient practice to develop a sensory-specific movement pattern during skill acquisition. Furthermore, we postulated that the relationship between feedback reliance and time spent in acquisition may be nonlinear. As such, the goal of the present study was to determine how the amount of time spent in practice modulates the formation of a sensory-specific movement pattern.

During the acquisition phase of the present experiment, absolute constant error did not decrease in relation to the time spent in acquisition (but see Note 3). However, in line with previous research, we did find that variable error decreased as a function of practice in both visual conditions, suggesting that some performance improvements did occur (see Schmidt & Lee, 1999, pp. 358–363). Given the nature of the task used in the present experiment, and the fact that our data suggest participants overshot and undershot the target location on subsequent trials, it seems reasonable that the acquisition improvements manifested as improvements in consistency (variable error).

The accuracy data (absolute constant error) from the transfer condition in the present experiment did not yield results consistent with the specificity hypothesis. Indeed, no difference in absolute constant error was observed between the FV and NV practice groups, an unsurprising finding given the practice effects observed for absolute constant error during the acquisition phase of the experi-

Table 1. Trend analysis indicating the F statistics and partial eta squared values for absolute constant error and variable error as a function of practice block during skill acquisition

Practice length No. of trials	Full vision ACE	Full vision VE	No vision ACE	No vision VE
10	1.12	0.26	0.25	4.53
50	0.85	6.66*	0.61	8.06**
100	0.81	6.23*	0.94	5.40*
200	1.09	6.46*	0.81	26.51***

Note. ACE = absolute constant error; VE = variable error; all reported trends are linear.
*$p < .05$.
**$p < .01$.
***$p < .001$.

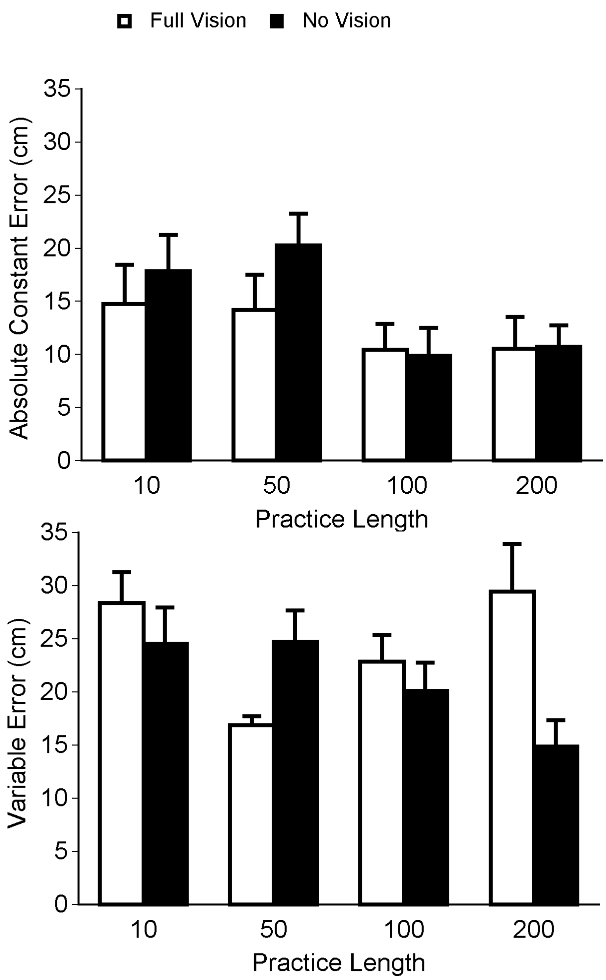

Figure 3. Transfer absolute constant error (cm) as a function of acquisition visual condition and practice length (top panel); transfer variable error (cm) as a function of acquisition visual condition and practice length (bottom panel). Error bars represent the standard error of the mean.

ment. However, analysis of variable error in the transfer condition did reveal a pattern of results somewhat consistent with the specificity hypothesis. Specifically, we found that variable error decreased as a function of practice in the transfer condition for the NV practice groups. Given that the feedback conditions were similar between the acquisition and transfer conditions for participants in these groups, this result fits the tenets of the specificity hypothesis. We did not find a similar pattern of results for the FV practice groups. Instead, our results indicated that initially variable error decreased as a function of practice length for FV participants. Conversely, our results revealed that variable error increased in the transfer condition following extended practice with vision (i.e., the FV200 group). These data suggest that visual feedback was not important, at least initially, for the development of a movement pattern for the experimental task. With that said, the results of the present experiment suggest that there is an increased reliance upon a specific source of afferent feedback (i.e., vision for the FV200 participants) after a sufficient amount of practice.

The results for the FV200 and NV200 groups support the specificity hypothesis and resemble previous findings demonstrating that participants develop a sensory-specific movement pattern with practice (e.g., Proteau, 1992; Proteau et al., 1987, 1998). The pattern of results observed in the present experiment could explain why only some of the previous studies exploring the specificity hypothesis found that reliance on feedback increased as a function of practice. Indeed, using only two amounts of practice to assess reliance on sensory feedback is inadvisable, as significant effects may be concealed due to a curvilinear relationship between practice and feedback reliance.

A Dual Process Account of Skill Acquisition

In the present study we found that throwing performance consistency (variable error) in the transfer condition improved from 10 to 100 trials of practice independent of the type of feedback available during skill acquisition. Conversely, after 200 practice trials our results indicated that participants had acquired a movement pattern reliant on a specific feedback source. At first glance these results seem to be partially opposed to the specificity hypothesis; however, we believe they are understandable if one considers a dual process account of skill acquisition. Khan, Franks, and Goodman (1998) proposed that participants improve both their control strategy (i.e., the motor program) and the efficiency of feedback processing during skill acquisition. In line with Khan et al.'s hypothesis, several studies (Park & Shea, 2003; Wright & Shea, 2001; Wulf & Schmidt, 1989) have demonstrated that, during the early stages of skill acquisition, participants in different experimental conditions demonstrate similar movement patterns, but as practice continues, the movement patterns begin to acquire characteristics specific to the practice condition experienced.

We believe our results support this dual process model of skill acquisition. However, our results suggest improvements to the control strategy and feedback processing occur—at least partially—in a sequential order. First, during the initial phases of learning, the control strategy (i.e., the motor program) for the task is stabilized. This idea is supported by the fact that performance variability in the transfer condition decreased in relation to time spent in acquisition (from 10 to 100 trials of practice) for and FV and NV participants. After these initial phases of learning (or perhaps at some point after amendments to the control strategy are underway), the efficiency of feedback processing is improved and the movement pattern for the task becomes reliant on a specific source of feedback. In other words, during the later phases of skill acquisition, the specificity hypothesis is valid and participants acquire a sensory-specific movement pattern. This second stage is supported by the fact that NV200 participants were significantly less variable than FV200 participants in the transfer condition. Further research is needed to investigate this dual process model of skill acquisition with regard to the timing of sequential adjustments to central control and the optimization of reliance upon sensory feedback.

Another interpretation of our results is that the initial decrease in reliance on visual feedback (i.e., FV10 vs. FV50, and FV100) may reflect improved refinements tothe motor program based on all available sources of information. After 100 trials of practice, further parameterization improvements in performance reflect an increasingly selective use of the most accurate source of information (i.e., the FV200 group in the current experiment; see Tremblay & Proteau, 1998), leading to an increasing reliance on visual feedback and a corresponding increase in endpoint variability. It is important that both of the hypotheses (i.e., the dual process model of skill acquisition and improved parameterization of the motor program) explain why some of the previous studies investigating the specificity hypothesis did not find differences in endpoint errors between experimental groups that experienced differing amounts of acquisition trials. In these instances, participants may still have been trying to improve their control strategy and were not yet at a point to improve their use of sensory feedback. Conversely, it may be that in previous studies (e.g., Tremblay & Proteau) there may not have been a sufficient number of acquisition trials separating the experimental groups for the movement pattern to become attuned to a specific source of feedback.

In conclusion, the results of the present study provide an explanation for why previous research investigating the specificity hypothesis failed to find performance differences related to the time spent in acquisition. The results of the present study stress the importance of using more than two levels of practice in assessing reliance on sensory information as a function of practice. In general, our results support the specificity-of-practice hypothesis, but suggest that it is valid only after sufficient practice. Specifically, our results allow us to suggest that reliance on a particular source of afferent feedback occurs only after the control strategy for a movement is optimized.

References

Abrams, R. A., & Pratt, J. (1993). Rapid aimed limb movements: Differential effects of practice on component submovements. *Journal of Motor Behavior, 25*, 288–298.

Bennett, S. J., & Davids, K. (1995a). The manipulation of vision during a powerlift squat: Exploring the boundaries of the specificity of learning hypothesis. *Research Quarterly for Exercise and Sport, 66*, 210–218.

Bennett, S. J., & Davids, K. (1995b). The effect of task constraints on the manipulation of visual information and the implications for the specificity of learning hypothesis. *Human Movement Science, 16*, 379–390.

Carlton, L. G. (1992). Visual processing time and the control of movement. In L. Proteau & D. Elliott (Eds.), *Vision and motor control* (pp. 3–31). Amsterdam: North Holland.

Desmurget, M., & Grafton, S. T. (2000). Forward modeling allows feedback control for fast reaching movements. *Trends in Cognitive Science, 4*, 423–431.

Elliott, D., & Allard, F. (1985). The utilization of visual feedback information during rapid pointing movements. *The Quarterly Journal of Experimental Psychology, 37*, 407–425.

Goodale, M. A., Pelisson, D., and Prablanc, C. (1986). Large adjustments in visually guided reaching do not depend on vision of the hand or perception of target displacement. *Nature, 320*, 748–750.

Khan, M. A., Franks, I. M., & Goodman, D. (1998). The effect of practice on the control of rapid aiming movements: Evidence for an interdependency between programming and feedback processing. *Quarterly Journal of Experimental Psychology, 51*, 425–444.

Krigolson, O. E., Van Gyn, G., Tremblay, L., & Heath, M. (2006). Is there feedback during visual imagery? Evidence from a specificity of practice paradigm. *Canadian Journal of Experimental Psychology, 60*(1), 24–32.

Lenoir, M. (2005). The role of visual input during rotation: The case of discus. *Biology of Sport, 22*(1), 53–66.

Oudejans, R. R. D., van de Langenberg, R. W., & Hutter, R. I. (2002). Aiming at a far target under different viewing conditions: Visual control in basketball jump shooting. *Human Movement Science, 21*, 457–480.

Park, J. H., & Shea, C. H. (2003). The independence of sequence structure and element production in timing sequences. *Research Quarterly for Sport and Exercise, 74*, 401–420.

Pew, R. W. (1966). Acquisition of hierarchical control over the temporal organisation of a skill. *Journal of Experimental Psychology, 71*, 764–771.

Proteau, L. (1992). On the specificity of learning and the role of visual information for movement control. In L. Proteau & D. Elliott (Eds.), *Vision and motor control* (pp. 67–103). Amsterdam: North Holland.

Proteau, L. (1995). Sensory integration in the learning of an aiming task. *Canadian Journal of Experimental Psychology, 49*, 113–120.

Proteau, L., & Cournoyer, J. (1990). Vision of the stylus in a manual aiming task: The effects of practice. *Quarterly Journal of Experimental Psychology, 42B*, 811–828.

Proteau, L., & Isabelle, G. (2002). On the role of visual afferent information for the control of aiming movements towards targets of different sizes. *Journal of Motor Behavior, 34*, 367–384.

Proteau, L., & Marteniuk, R. G. (1993). Static visual information and the learning and control of a manual aiming movement. *Human Movement Science, 12*, 515–536.

Proteau, L., Marteniuk, R. G., Girouard, Y., & Dugas, C. (1987). On the type of information used to control and learn an aiming movement after moderate and extensive training. *Human Movement Science, 6*, 181–199.

Proteau, L., Marteniuk, R. G., & Lévesque, L. (1992). A sensorimotor basis for motor learning: Evidence indicating specificity of practice. *Quarterly Journal of Experimental Psychology A: Human Experimental Psychology, 44A*, 557–575.

Proteau, L., Tremblay, L., & DeJaeger, D. (1998) Practice does not diminish the role of visual information in online control of a precision walking task: Support for the specificity of practice hypothesis. *Journal of Motor Behavior, 30*, 143–150.

Robertson, S., Collins, J., Elliott, D., & Starkes, J. (1994). The influence of skill and intermittent vision on dynamic balance. *Journal of Motor Behavior, 26*, 333–339.

Saunders, J. A., & Knill, D. C. (2003). Humans use continuous visual feedback from the hand to control rapid reaching movements. *Experimental Brain Research, 142*, 341–352.

Schmidt, R. A. (1975). A schema theory of discrete motor skill learning. *Psychological Review, 82*, 355–386.

Schmidt, R. A., & Lee, T. D. (1999). *Motor control and learning: A behavioral emphasis* (3rd ed.). Champaign, IL: Human Kinetics.

Tremblay, L., & Proteau, L. (1998). Specificity of practice: The case of powerlifting. *Research Quarterly for Exercise and Sport, 69*, 284–289.

Whiting, H. T. A., Savelsbergh, G. J. P., & Pijpers, J. R. (1995). Specificity of motor learning does not deny flexibility. *Applied Psychology: An International Review, 44*, 315–332.

Wright, D. L., & Shea, C. H. (2001). Manipulating generalized motor program difficulty during blocked and random practice does not affect parameter learning. *Research Quarterly for Exercise and Sport, 72*, 32–38.

Wulf, G., & Schmidt, R. A. (1989). The learning of generalized motor programs: Reducing the relative frequency of knowledge of results enhances memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 23, 987–1006.

Yoshida, M., Cauraugh, J. H., & Chow, J. W. (2004). Specificity of practice, visual information, and intersegmental dynamics in rapid-aiming limb movements. *Journal of Motor Behavior, 36*, 281–290.

Zelaznik, H. N., Hawkins, B., & Kisselburgh, L. (1983). Rapid visual feedback processing in single-aiming movements. *Journal of Motor Behavior, 15*, 217–236.

Notes

1. Further, the terms used to describe the amount of practice may be misleading, as how does one know how many trials compose a "brief" or "extended" amount of practice.
2. Pilot data in the present study indicated a movement time between 750 and 1,000 ms for the throwing task.
3. We converted the raw data to absolute error scores and conducted trend analyses on these data for the full- and no-vision 50, 100, and 200 groups. Analysis revealed that absolute error for each group decreased as a function of practice ($p < .05$). We believe the absolute constant error scores masked repeated over- and undershooting of the target during the acquisition phase.

Authors' Notes

The authors thank the Michael Smith Foundation for Health Research and the National Sciences and Engineering Research Council of Canada for supporting this research. The authors also thank Andrew Grant for his help with data collection. Please address all correspondence concerning this article to Olav E. Krigolson, Department of Psychology, University of British Columbia, 2136 West Mall, Vancouver, British Columbia, Canada V6T 1Z4.

E-mail: krigolson@psych.ubc.ca