The manipulation of vision during the powerlift squat: Exploring the Boundaries of the Specificity of Learning Hypothesis

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The available information for controlling a multidegree-of-freedom sport action was manipulated in 2 experiments. In the first, 10 intermediate lifters were participants; for the second, 8 skilled and 8 less skilled lifters were observed. Three single repetitions of a powerlift squat were performed under 3 vision conditions (i.e., full, ambient, no vision). The less skilled and intermediate lifters’ technical performance decreased significantly with the removal of visual information. There was no detrimental effect in the skilled group. Despite the differing information constraints, skilled lifters exhibited a high level of positioning accuracy and timing consistency across conditions. These data fail to support the theoretical predictions of the specificity of learning hypothesis. The differences between the task constraints in this study and those in manual aiming investigations may represent a boundary to the current propositions of the specificity of learning hypothesis.

Key words: specificity of learning, visual feedback, movement control

Much debate in the motor learning literature has been focused on the issue of the specificity of learning (e.g., Barnett, Ross, Schmidt, & Todd, 1973; Henry, 1968). The general hypothesis is that because tasks are relatively independent, performing skills in conditions that differ from those in which original learning occurred will emphasize different motor abilities. The implication is that the conditions of practice should closely match performance conditions in order to reduce the negative effects of transfer.

Recently, Proteau and colleagues (e.g., Proteau, 1992; Proteau, Marteniuk, Girouard, & Dugas, 1987) introduced a revised version of the specificity of learning hypothesis. Contrary to traditional motor learning theories (e.g., Fleishman & Rich, 1963), the central prediction is that learning does not result in a shift in reliance away from one source of stimulus information (e.g., visual) to another (e.g., kinesthetic). Rather, skilled performance is characterized by an increased dependence on the specific sources of information available during acquisition. Learning is seen as a continual refinement of interrelationships among tightly integrated feedback sources. Consequently, if this network is disrupted by the manipulation of relevant feedback sources, performance deteriorates.

Empirical support for this theoretical prediction was found in Proteau et al.’s (1987) experiment on manual aiming. Participants were required to move a handheld stylus a distance of 90 cm to a target located at the center of a data-recording tablet. The acquisition conditions included performance with vision of the performing limb and target or with vision of the target alone for either a moderate (200) or extensive (2,000) number of trials. Knowledge of results (KR) concerning movement accuracy on both the x and y axes (in millimeters) and movement time (in milliseconds) was provided after each trial. Following the acquisition period, participants were always transferred to a condition where only the target was visible and no KR was given. The results suggested that transfer to such a condition caused a significant increase in aiming error regardless of the number of practice trials. Significantly, those participants who received most practice with vision of the limb and target were most vulnerable to the transfer condition.

Further work by Proteau, Marteniuk, and Lévesque (1992) also supported the specificity of learning hypothesis. It was found that the addition of visual feedback on the ongoing limb and surrounding environment after 1,200 practice trials in a target-only condition led to a significant performance decrement. On the basis of these and other data, Proteau (1992) ar-
gued against the suggestion by Fleishman and Rich (1963) that the utility of sensory feedback decreases as a function of practice or task expertise (see also Cox & Walkuski, 1988, who failed to replicate Fleishman & Rich's, 1965, results). Rather, it was proposed that "...withdrawing or adding a significant source of information after a period of practice where it was respectively present or absent results in a deterioration of performance" (Proteau, 1992, p. 96).

Recently, however, Whiting and Savelsbergh (1992) pointed to a wealth of data in the ball catching literature that appear to raise questions over the generality of the specificity of learning hypothesis. Their ball catching data indicated that when transferred to a full-light posttest condition after short and long training periods in the dark (only luminous ball visible), less skilled catchers continued at a level of performance they had previously achieved in a full-light pretest condition. That is, although the removal of visual feedback of the environment and catching limb resulted in an expected performance decrement, its addition did not adversely affect catching performance, contrary to Proteau's (1992) theoretical predictions.

Further contrasting evidence was reported by Davids and Stratford (1989). Employing a novice-expert paradigm (i.e., introducing the visual manipulation as a within-subjects factor), they indicated that the removal of vision of the responding limb resulted in significantly more spatial errors for a group of less skilled catchers only. For a skilled group, the removal of vision of the responding limb after extensive practice did not result in a significant performance decrement. It appears that although vision of the responding limb was important early in learning, extensively practiced participants could, when necessary, achieve accurate arm positioning in its absence. The implication is that after extended practice in normal visual conditions, participants had experienced a shift away from visual monitoring and toward kinesthetic monitoring of the catching hand (see also Savelsbergh & Whiting, 1988; Savelsbergh, Whiting, & Pipers, 1992).

It is clear that the proposal of increased reliance on the specific sources of information available during learning in the laboratory-based manual aiming studies are difficult to reconcile with some ball catching data (e.g., Davids & Stratford, 1989; Whiting & Savelsbergh, 1992). How may the discrepancy be explained? One solution to this problem may lie in the fact that although both tasks are forms of interceptive actions, each possesses a number of distinct task constraints which mediate the influence of the available informational modalities.

Carlton (1981) demonstrated that the transport phase of the manual aiming movement is regulated by peripheral or ambient vision, whereas the final homing-in phase on the target is under central visual control (kinesthesia is available during both phases). In the studies by Proteau and colleagues (e.g., Proteau, 1992; Proteau et al., 1987; Proteau et al., 1992), participants were clearly unable to maintain accurate manual aiming performance with either the removal and addition of visual information on the limb.

In fact, data from a more recent study by Temprado, Proteau, and Violedent (1994) indicated that in manual aiming tasks that emphasize control in relation to a specific point in space, it is the final homing-in phase that is most affected by the removal of vision. Because accurate manual aiming performance appears dependent on the availability of central vision, it would seem that although kinesthesia does play a role in providing movement control information, this task emphasizes a bias toward the visual modality (Klein, 1977; see also Proteau et al., 1992, for a similar interpretation).

The implication is that although the evidence for the specificity of learning hypothesis receives strong support in an experimental task that requires participants to track the position of the limb in relation to an external reference point in central vision, it may not be generalizable to other tasks with different constraints on the use of vision and kinesthesia. For example, as suggested earlier, it does not seem to explain the data from the externally paced act of one-handed ball catching which requires the tracking of a dynamic target in central vision and the monitoring of the limbs in the periphery. The question arises, therefore, whether the specificity of learning hypothesis generalizes to a self-paced task which requires the position of the limbs to be regulated in relation to an internal reference point on the basis of ambient vision and kinesthesia.

A self-paced sport task that fits into such a classification is the powerlift squat. Technically, the lifter assumes an upright standing position with the bar held horizontally across the back of the shoulders. The hands and the fingers grip the bar with the feet flat on the platform and the knees locked. Upon the signal from a judge, the lifter descends toward a squat position. From a motor control perspective, in the first part of this biphasic action, the lifter is required to appropriately modulate muscular forces such that the top surface of the thigh at the hip is below the top surface of the thigh at the knee. When this has been achieved, the lifter begins the ascent to the upright position. Successful squatting performance is dependent on strength, balance, and the correct spatiotemporal application of muscular forces. Squatting to a specific endpoint in space may be considered a form of aiming task in that the position of the hip relative to the knee must be carefully modulated in order to achieve a precise value.

In relation to the specific theoretical issue addressed in this paper, it should be noted that lifters in
the competitive environment do not have access to central visual information on the position of their limbs or the relative end target (i.e., the location where the top of the thigh at the hip is below the top of the thigh at the knee). Still, it has been demonstrated that expert lifters are capable of a high degree of technical accuracy under such informational constraints (see McAulhlin, Lardner, & Dillman, 1978). Precise control of balance and posture, as well as the spatiotemporal patterning of muscular forces, appears to be regulated by a combination of ambient vision and kinesthesia. In such tasks, the addition of visual information, while of some benefits to movement control, may not cause a bias away from the acquired kinesthesia. Further, with the removal of vision, attuned participants may be able to gain sufficient regulatory information from a logical alternative (e.g., kinesthesia). The removal or addition of vision would therefore not be expected to result in a performance decrement in this particular sport task.

In summary, the present body of data in support of the specificity of learning hypothesis emanates only from tasks in which the visual and central visual modalities play the dominant role (e.g., manual aiming; Proteau et al., 1987; linear positioning: Reeve & Mainor, 1983). Some further questions have been raised concerning the generalizability of the hypothesis to tasks such as one-handed catching (Whiting & Savelbergh, 1992).

The aim of this study was to examine the generalizability of the theoretical predictions of the specificity of learning hypothesis to the powerlift squat. A study explicitly dealing with learning was not considered feasible with a task such as the powerlift squat because changes in physiological factors, such as strength, fatigue, and flexibility, may have had too strong a mediating effect on task performance. The use of skilled, intermediate, and less skilled groups of participants offered an alternative method of observing the mediating effects of specific feedback manipulations on squatting performance as a function of practice. Furthermore, it is arguable that because the visual manipulation was introduced as a within-subjects factor in the present study, any observed differences in performance under different environmental conditions may be somewhat reduced as compared to effects obtained with a between-subjects design (Poulton, 1981).  

Two general hypotheses, in line with the theoretical propositions of the specificity of learning hypothesis, were tested. First, it was expected that the manipulation of visual information would lead to performance decrements in all groups of lifters. The second hypothesis examined the prediction that the effects of the manipulations would be greater in the more skilled groups because of the more extensive practice they had undergone.

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**Experiment 1**

**Method**

**Participants**

Ten male powerlifters (\(M_{\text{age}} = 20.5\) years, \(SD = 3.1\)) volunteered to be participants. All were classified as intermediate level performers in the powerlift squat and were recruited from a local weightlifting club. The classification was based on their experience with weight training and/or bodybuilding. Participants had engaged in these activities for 2 to 5 years. After the experimental session, participants completed a questionnaire aimed at identifying their normal squatting conditions and their perceptions of the experimental conditions.

**Design and Procedure**

Nine single repetitions of the powerlift squat, with a load of 50% of a one-repetition maximum (1-RM), were randomly performed under the three vision conditions. The conditions were (a) full vision (FV)—squatting with the addition of ongoing visual information on the position of the limbs (and therefore relative target endpoint) in a full-length mirror situated on the front-facing wall; (b) ambient vision (AV)—squatting while focusing on a fixed point overhead (i.e., black industrial tape 2 cm in width) to facilitate orientation and to replicate the competitive environment (the mirror was occluded for this condition); and (c) no vision (NV)—squatting while wearing an unobtrusive blindfold to exclude all possible sources of visual information.

All squats were executed within a squatting safety cage, using an Olympic barbell, plates, and collars (i.e., as used in competition and in training gymnasiums). A video camera mounted on a tripod was positioned 8-m perpendicular to the participants’ sagittal plane (additional illumination was not required).

Prior to lifting, all participants completed a consent form and warmed up thoroughly. They were instructed to follow their usual warm-up program in order to reduce the possible artificial nature of the experimental setup. The task requirements were explained both verbally and in written form. Participants were habituated by performing five practice squats in each of the conditions prior to testing. All squats were performed in-line with the technical rules of the 1992 Men’s World Powerlifting Championships. Participants were instructed to assume the upright position, with the barbell held horizontally across the shoulders. An experimenter was situated behind them in order to offer assistance if required. With the video camera recording the action, one single repetition was performed upon the
command "squat." Having completed the lift, they were instructed to rack the bar. Although no temporal limit was enforced, participants were instructed not to intentionally slow the descent in order to home-in on the required endpoint location. Further repetitions were performed at 2-min intervals. In the AV condition, participants were instructed to focus on the guide point provided (i.e., black industrial tape) above head height on the front-facing wall. To ensure safety in the NV condition, the blindfold was fitted and removed with the participant in the upright position. To account for any possible systematic error, the lifts for each condition were counterbalanced across conditions.

At the 1992 Men’s World Powerlifting Championships, there were 10 possible causes for disqualification. Of these, Rule 3 is of key interest to the present study: Failure to bend the knees and lower the body until the top surface of the thighs at the hip are lower than the top surface of the thighs at the knee. A high degree of spatiotemporal accuracy was required to achieve the correct endpoint location. The scoring system for the two experiments in this study was based on this technical requirement (see Figure 1). Participants were informed both verbally and in the consent form that performance was scored on the accuracy of their positional ability and not on the relative ease or speed of the lift.

**Performance Measure**

In the competitive environment, each of the three judges awards a "good" lift a white light and a "bad" lift a red light. Two white lights are required for the lift to be judged successful. This three-light system formed a natural rationale for the scoring system of the present study. In Figure 1, it can be seen that Position A was scored a 0 because clearly no white lights would be given. Position B was scored a 2. The rationale for this measurement proposal is that the subjective nature of the scoring in competitions (i.e., three individual judges scoring the lift in real time) may result in a "successful lift" classification being awarded on some occasions. Therefore, although not a perfect lift, it may still be awarded two white lights and hence a "good" classification. For Position C, the score of 3 was awarded. This was considered as the ideal stance according to the technical rules and hence three white lights would result. For a position comparable to D, a score of 1 was given. If the lifter assumed such a position with 100% of a 1-RM, the possibility of returning to the upright position would be markedly reduced. Therefore, Position D was not scored as highly as Positions B or C.

**Results and Discussion**

The questionnaire data indicated that 90% of the participants trained under FV conditions. Further, 90% of the participants reported the FV condition to offer an advantage in terms of movement control. The AV and NV conditions were reported to offer no such advantage.

Two experienced powerlifters (mean years in powerlifting = 7) independently scored the video recordings of each participant’s lifts. The repeated measures design of this study necessitated intrajudge and interjudge reliability checks. The intrajudge reliability score was obtained by scoring the squats on two separate occasions. The mean value for the data (three trials per condition per participant) was submitted to repeated measures analysis of variance (ANOVA) and interclass correlation. An interclass correlation coefficient of $R = .92$ was obtained. Interjudge reliability was provided by conducting a Subjects x Raters ANOVA on each of the lifts, and an intraclass correlation coefficient of $R = .96$ was indicated.

The data on the three trials per condition were then pooled and submitted to a one-way ANOVA with repeated measures on the condition factor. Effect sizes (Cohen’s $d$) were calculated to examine the meaningfulness of any significant differences between conditions. A main effect for condition was noted, $F(2, 18) = 6.88$, $p < .01$, $\epsilon = .98$. A Tukey HSD post hoc test revealed significant differences between the FV and AV conditions ($d = .71$) and between the FV and NV conditions ($d = 1.07$).

Performance in the FV condition ($M = 2.40$, $SD = .44$) was significantly better than in both the AV condition ($M = 2.00$, $SD = .66$) and the NV condition ($M = 1.86$, $SD = .55$). The data offer preliminary support for Proteau and colleagues’ (e.g., 1987, 1992).
theoretical predictions. After moderate practice in FV environments, the progressive removal of visual information resulted in a consecutive performance decrement (see Figure 2). Participants were seemingly reliant on the visual information provided from the mirror and surrounding environment. Therefore, while the demands of the powerlift squat do not seem as severe as those required in manual aiming and one-handed catching tasks, these data imply that the spatiotemporal constraints of the squatting action still necessitate visual information concerning the limb position and target endpoint.

A question concerning the role played by extensive practice still remains unanswered. It may be that for moderately skilled participants, kinesthesia alone is not adequate for maintaining precise control of the squat. With the removal of vision, participants were left with an inadequate source of movement-produced feedback and hence there was a performance decrement. However, after extensive practice, kinesthesia may become more important in regulating squatting performance. That is, highly skilled participants may have developed the means to perform in both vision and no-vision conditions. In order to provide a clearer understanding of the changes in motor control as a function of practice, it was necessary to introduce skill level as an additional independent variable. By the nature of their training environment, intermediate level lifters were not subjected to the addition of visual information. With highly skilled competitive lifters, who train in an ambient visual environment, it would be possible to further examine the predictions of Proteau and colleagues (1987, 1992) concerning the effects on performance of adding a relevant source of stimulus information. A more detailed analysis of the temporal parameters was also included to facilitate the validation of the scoring system and to add support to the experimental findings.

Experiment 2

Method

Participants

Eight skilled (\(M\) age = 24.5 years, \(SD = 2.3\)) and eight less skilled (\(M\) age = 22.3 years, \(SD = 2.7\)) male powerlifters volunteered to be participants. As in Experiment 1, all participants were recruited from a local weightlifting club. Skilled participants were classified according to experience in powerlifting competitions. They had regularly competed in and achieved a top 5 ranking at a national powerlifting competition within the previous 2 years. The less skilled classification was based on experience with weight training and/or bodybuilding. Participants had engaged in these activities between 1 and 3 years. They were not current, nor had ever been, competitive performers. After the experimental session, participants completed a questionnaire aimed at identifying their normal squatting conditions and their perceptions of the experimental conditions.

Design and Procedure

The two groups of participants randomly performed nine single repetitions of the powerlift squat, with a load of 50% of a 1-RM under the three vision conditions. All squats were again executed within a squatting safety cage, using an Olympic barbell, plates, and collars (i.e., as used in competition and in training gymnasiums). A video camera mounted on a tripod was positioned 8 m perpendicular to the participants’ sagittal plane (additional illumination was not required).

Performance Measure

The three-light scoring system described in Experiment 1 was used to score the participants’ lifts. In addition, the video recordings of the performance of 2 experienced and 2 less experienced participants were randomly selected and subjected to two-dimensional coordinate digitization. The greater trochanter of the left lower extremity was digitized at a rate of 25 Hz. The coordinate data were then smoothed using a generalized quintic spline smoothing process reported by...
Bartlett, Challis, and Yeaton (1992). As the scoring system was based on the participants’ ability to descend to the correct endpoint location, it may not have necessarily indicated changes in the temporal patterning of the biphasic squatting action. Analysis of the mean and standard deviation of the descent time provided a measure of the possible within-group temporal changes that occurred when the available information was manipulated.

Results and Discussion

The questionnaire data indicated that 100% of the less skilled participants trained under FV conditions, while 25% also reported training under AV conditions. Further, 87.5% reported the FV condition to offer an advantage in terms of movement control. The AV and NV conditions were reported to offer no such advantage. All of the skilled participants indicated that they trained under AV conditions. No advantage was reported regardless of condition.

Two experienced powerlifters (mean years in powerlifting = 7) independently scored the video recordings of each participant’s lifts. Intrajudge and interjudge estimates of reliability were obtained by the same methods used in Experiment 1. For intrajudge reliability, an intraclass correlation coefficient of $R = .96$ was obtained. An intraclass correlation coefficient of $R = .95$ was obtained for interjudge reliability.

The data were then submitted to a 2 x 3 (Skill Level x Condition) ANOVA with repeated measures on the condition factor. Effect sizes (Cohen’s $d$) examined the meaningfulness of any significant differences. An interaction of Skill Level x Condition was found, $F (2, 28) = 15.95$, $p < .01$, $\epsilon = .80$. Further analysis demonstrated that the less skilled participants differed in performance according to condition, $F (2, 28) = 46.94$, $p < .01$. Simple main effects and Tukey HSD post hoc tests revealed that for the less skilled group, FV was greater than both AV ($d = 1.26$) and NV ($d = 2.89$) and that AV was greater than NV ($d = 1.36$). No differences were observed across conditions for the skilled group. Simple main effects for group in the AV condition, $F (1, 42) = 9.80$, $p < .01$, and in the NV condition, $F (1, 42) = 33.93$, $p < .01$, were also noted. In the AV and NV conditions, where both the skilled and less skilled participants had access to the same perceptual information, the skilled participants clearly performed more successfully than the less skilled participants.

There was no significant difference in the accuracy of skilled participants’ performance across all three conditions (see Table 1). Near perfect spatial performance was exhibited regardless of condition. The addition of visual feedback on the location of the effectors had no adverse effects on performance. The removal of ambient visual information also resulted in no performance decrements. The less skilled lifters’ performance decreased significantly as vision was progressively degraded. In contrast to the skilled group, they were seemingly dependent on constant access to full visual information for successful squatting performance.

In relation to this argument, sample data on the descent time during the important homing-in phase of the squat for 2 participants from the skilled and less skilled groups are shown in Table 2. These data offer some support for the findings obtained from the spatial analysis of the task. The skilled participants appeared to exhibit more consistent temporal performance, as evidenced by the smaller standard deviations, regardless of the visual manipulation. The timing of the less skilled participants was, in general, more variable.

**Table 1. Performance scores for groups of skilled and less skilled powerlifters across the three vision conditions**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Skilled group</th>
<th>Less skilled group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M$</td>
<td>$SD$</td>
</tr>
<tr>
<td>Full vision (FV)</td>
<td>2.83</td>
<td>0.25</td>
</tr>
<tr>
<td>Ambient vision (AV)</td>
<td>2.79</td>
<td>0.30</td>
</tr>
<tr>
<td>No vision (NV)</td>
<td>2.62</td>
<td>0.45</td>
</tr>
</tbody>
</table>

**Table 2. Time of descent (in seconds) for randomly sampled skilled ($n = 2$) and less skilled participants ($n = 2$)**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Skilled sample</th>
<th>Less skilled sample</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Participant 1</td>
<td>Participant 2</td>
</tr>
<tr>
<td></td>
<td>$M$</td>
<td>$SD$</td>
</tr>
<tr>
<td>Full vision (FV)</td>
<td>1.27</td>
<td>0.06</td>
</tr>
<tr>
<td>Ambient vision (AV)</td>
<td>1.30</td>
<td>0.10</td>
</tr>
<tr>
<td>No vision (NV)</td>
<td>1.36</td>
<td>0.13</td>
</tr>
</tbody>
</table>

General Discussion

In the current study, the data indicate that the squatting performance of highly skilled participants was not adversely affected by the manipulation of the available visual information. They exhibited near perfect spatiotemporal performance regardless of condition.
However, for the less skilled and intermediate groups, vision was clearly a prerequisite for the regulation of squatting performance. Their spatiotemporal performance decreased significantly with the sudden removal of visual information (see Figure 2). It is somewhat interesting to note that although there was no significant difference between the performance of the intermediate group in the AV and NV conditions, the less skilled participants were significantly less accurate in the NV condition. Closer inspection of the data suggests that although both groups exhibited similar performance in the AV condition, the less skilled participants showed a greater performance decrement in the NV condition. While both groups found the addition of a visual focal point 3 m in front of them to provide only a limited degree of movement control information, its removal caused a significantly greater disruption to the performance of the less skilled participants. From a practical perspective, the finding that the focal point affords only a limited source of movement control information may have important implications. In a powerlifting competition, a specific focal point is not provided. Rather, lifters are required to discover their own focal point, which by the nature of the competitive environment (i.e., the lifter assumes a position on a stage which faces the area for the audience) would always be at a distance greater than 5 m.

This paper highlights data from a self-paced sport task, which may be construed as somewhat difficult to interpret according to the predictions of the specificity of learning hypothesis advanced by Proteau and colleagues (1987, 1992). The removal and addition of vision did not have deleterious effects on the squatting performance of participants extensively practiced in AV conditions. They were not limited to replicating a precise movement pattern under a condition in which the task was predominantly practiced (i.e., ambient vision). Rather, the data support the view that the utility of visual information, although important for accurate movement regulation early in learning, decreases as a function of task expertise. When necessary, skilled participants were able to operate effectively under conditions of varying informational constraints. Preliminary support is therefore offered for the notion of a more flexible operating system which is not strictly dependent on the specific feedback available during learning (Whiting & Savelbergh, 1992).

The discrepancy between these data and the findings of Proteau and colleagues (1987, 1992) may be explained by the relatively distinct task and environmental constraints of both actions. Unlike the manual aiming task, precise visual information on the limbs and movement endpoint was not accessible during the squatting action due to task constraints (e.g., the lifter assumes an upright position with the bar held horizontally across the back of the shoulders with the hands and the fingers gripping the bar). With practice, participants discovered that visual feedback is less adequate and that kinesthesia may provide a more accurate source of information for movement control. The nature of the squatting task may have assisted the development of internally located spatiotemporal regulation by increasing awareness of kinesthetic feedback. It is a multidegree-of-freedom action that produces alterations in angular acceleration and head orientation that readily surpass the vestibular threshold levels (Birren, 1945). Moreover, a greater movement resistance is obtained with the addition of weight. When all visual information was removed, skilled participants appeared able to gain sufficient regulatory information from kinesthesia alone. However, less skilled participants did not seem as fully attuned to kinesthesia and were not capable of achieving the same level of control without vision. Evaluation of the effect size analyses for the comparisons across conditions indicates that they were possibly becoming more attuned to kinesthesia.

On the other hand, with the addition of visual information, the attention of skilled participants did not seem to be biased away from the previously attuned kinesthesia and thus accurate performance was maintained. The implication is that contrary to the idea of increasing reliance on the specific feedback available during acquisition, participants learned to exploit sources of information other than vision. As previously suggested, the data in support of the notion of increasing specificity as a function of practice seem more applicable to an experimental task in which participants are able to monitor both the position of the limb and an external reference point in central vision. Perhaps manual aiming tasks emphasize a bias toward this typically dominant modality. It must be stated, however, that the data reported here represent preliminary evidence on this relevant distinction. Further research, concerning tasks in which the dominance of other sensory modalities (i.e., kinesthesia and audition) can be manipulated, is currently being undertaken in order to provide a clearer understanding of the changes that occur in motor control as a function of practice.

An alternative interpretation of the data is that the less stringent margin of error in squatting reduces the importance of visual information and permits accurate spatiotemporal control on the basis of kinesthesia alone. A similar interpretation has been invoked to account for the lack of a detrimental effect of limb occlusion on tennis volleysing performance (Davids, Palmer, & Savelbergh, 1989) and on foot control in soccer passing (Barfield & Fischman, 1990) of novice and expert participants. However, such an explanation should not be considered appropriate for the data of the present study because vision was found to be important for less skilled and intermediate participants. Still, it is worth noting that the accuracy requirements of the manual
aiming task used by Proteau and colleagues (1987, 1992) are more stringent than those of both one-handed catching and squatting (e.g., in manual aiming, participants were recording root mean square error values between approximately 7 and 20 mm in relation to a target of 0.5 mm in diameter). The data presented here, and elsewhere using sport-related tasks, highlights the need for research into more everyday activities which accommodate less stringent margins of tolerable error.

In summary, evidence has been presented which appears to support the notion of a boundary to the specificity of learning hypothesis of Proteau and colleagues (1987, 1992). The performance of highly skilled athletes may not be adversely affected by the removal or addition of visual information in tasks, such as the powerlift squat, which do not typically permit access to ongoing visual information from the limbs and are therefore not biased toward this modality. Moreover, the performance of these tasks does not seem exclusively dependent on the sources of information available early in learning (i.e., ambient vision). Rather, skilled lifters seem able to exploit available kinesthetic information sources to aid accurate movement regulation. When necessary, it appears that they are able to perform effectively under conditions of different informational constraints. As such, it is suggested that the theory of Proteau and colleagues, although valid for the laboratory-type tasks studied, does not give a full account of the changes in control that occur as a function of practice in this category of sport task.

A theoretical question raised by the comparison of the current data with those from the manual aiming studies of Proteau and colleagues (1987, 1992) is whether visual information is important or necessary for controlling movement in certain types of tasks. In manual aiming, vision always appears to be necessary due to the constraints of the task, and its manipulation typically results in large effects on performance. In this study, it is possible that the group of skilled lifters found that visual information was important but not necessary for movement control in the powerlifting task. In fact, it may be the case that they had learned not to rely on visual information alone to modulate the descent to the target position and postural control during this task due to the performance constraints of competition. On the other hand, the less skilled lifters were affected by the withdrawal of vision, suggesting that they found visual information necessary at that stage of learning. One assumption is that the skilled lifters may have been able to “redevelop” their internalized network store to exploit other sources of information, rather than vision, for regulating the movement. However, a direct test of this suggestion was beyond the scope of the present study. It must also be borne in mind that the participants were lifting at only 50% of normalized resistance. The argument that the network store of the skilled participants may no longer have contained visual information needs to be tested by research in more stringent task conditions.

The current data suggest that the identification of actions in which visual information is an important or necessary source of support for movement regulation is a nontrivial task for researchers interested in the specificity of learning propositions. Clearly, further work is necessary to continue the task of probing the boundaries of the specificity of learning hypothesis in sport contexts.

References


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**Note**

1. However, it should be noted that the potential for contamination of the data by transfer effects represents a danger in within-subjects designs.

**Authors’ Notes**

This study was completed by the first author in partial fulfillment of a doctoral degree at the Manchester Metropolitan University under the supervision of the second author. The authors would like to acknowledge the help of Professor Les Burwitz in the development of this study. Please address all correspondence concerning this article to Simon Bennett, Division of Sport Science, Alsager Faculty, The Manchester Metropolitan University, Hassall Road, Alsager ST7 2HL, United Kingdom.

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