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Progressive Reduction Versus Fixed Level of Support During Training: When Less is Less

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Abstract

Previous empirical and theoretical work suggests that effective skill acquisition requires movements to be generated actively and that learning new skills supports the acquisition of prospective control. However, there are many ways in which practice can be structured, that may affect the acquisition and use of prospective control after training. Here, we tested whether the progressive modulation and reduction of support during training was required to yield good performance after training without support. The task was to use a stylus to push a bead over a complex 3D wire path. The support “magnetically” attracted and held the stylus onto the wire. Three groups of adult participants each experienced one of three training regimes: gradual reduction of magnetic attraction, only a medium level of attraction, or low magnetic attraction. The results showed that use of a single (medium) level of support was significantly less effective in yielding good performance with low support after training. Training with low support yielded post-training performance that was equally good as that yielded by training with progressive reduction of support; however, performance during training was significantly poorer in the former. Thus, less support during training yields effective learning but more difficult training sessions. The results are discussed in the context of application to training with special populations.

1. INTRODUCTION

The process of learning a new perceptuo-motor task has been characterized as a matter of first producing an approximation to the task specific movements, one that is qualitatively correct if quantitatively lacking (Newell, 1991; Swinnen, 1996). Quantitative improvement follows with practice. How best to foster improvement, either qualitative or quantitative, remains unclear. However, there is a growing body of evidence supporting the conclusion that the active generation of movements is required to yield effective learning of the corresponding skill (e.g. Snapp-Childs, Casserly, Mon-Williams, & Bingham, 2013; Beets et al., 2012; Liu, Cramer & Reinkensmeyer, 2006; Reinkensmeyer & Patton, 2009; Wong, Kistemaker, Chin & Gribble, 2012). Actively generated movement entails prospective control. That is, movements are future oriented – the actor uses perceptual guidance that

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anticipates each successive phase of a skilled movement allowing requisite control to be in place and operating as each new phase of a movement is entered. For instance, when driving a car or guiding a bead around a complexly curved wire, each turn must be anticipated and suitable control must begin before the curve is actually entered (Marchal-Crespo, McHughen, Cramer & Reinkensmeyer, 2010; Snapp-Childs et al., 2013).

The requirement for active generation of movements in the context of training for movement skill acquisition poses a problem for training methods (especially when training individuals with motor impairments). Passive modeling is ineffective, so how should the learner be guided? The answer is to provide support that allows the learner to produce task specific movements effectively while requiring those movements to be actively generated. Support can then be gradually reduced and eventually eliminated as the learner acquires the ability to perform the task. This was the approach taken by Snapp-Childs et al. (2013b) when formulating a method for training improved manual control by children of a stylus in drawing and handwriting tasks. They made a wire path magnetic so that the stylus was held onto the wire in a 3D tracing task, allowing the learner to concentrate on moving the stylus to push the bead around the curved wire path. The goal of the training was to yield better compliance control in the performance of drawing and writing. The best way to move the stylus along the wire path with the magnetic attraction was to move compliantly so as to better sense the wire and allow it to guide the movement. Snapp-Childs et al. (2013a) found that the method yielded improved compliance control of the movements but only when movements were performed actively. However, only one form of active practice was tested – progressive reduction of support. It is well known that the structure of practice is important and that training schedules should be tailored to suit the goals of the learner (e.g. see Keetch et al. 2005). So, it remains unclear whether the progressive-reduction training schedule was optimal.

Present study

The purpose of the present study was to determine how variations in practice structure affect the efficacy of motor learning. Specifically, we examined whether a single level of support yields performance improvements equivalent to those yielded by the regimen of progressively modulated support. To do this, we tested three groups of adult participants who trained on a 3D tracing task. The first group experienced the training regimen used in the previous studies. They started with a high level of support (strong magnetic attraction) that was progressively reduced within each training session. The second group experienced a single medium level of support throughout the training. A third group experienced a single level of low support throughout the training.

First, we made predictions regarding the pre- and post-training performances. To anticipate which regimen might yield more effective learning requires an estimation of the contribution of errors to learning. If having too many errors is disruptive, then the progressive regimen might be expected to be better overall, followed by the medium support level and then the low support level. On the other hand, if the specificity of practice is important (Proteau, 1992), that is, that one learns what one has experienced in training, then the progressive and low support regimens would be required to yield significant improvement in performance of

the task with low support, because both of these training regimens include practice with low support. We predicted that, after training, both the progressive and the low support regimens should yield good performance on the low support conditions; while the moderate support regimen should not. Next, we made predictions regarding the performance during training. The progressively modulated support was designed (and expected) to keep the rate of error production fairly low. In contrast, using a single level of moderate support was expected to produce higher error rates than the progressive training regimen at first and lower rates at the end. The low support training regimen should yield very high error rates to start, and while the errors should decrease over training, they were also expected to remain higher overall than the other training regimens.

2. METHODS

2.1 Participants

Thirty-six adults participated in this experiment. Twelve participants were assigned to each of three groups (progressive support: 5 females, 7 males, 20–35 years old; medium support: 9 females, 3 males, 19–32 years old; low support: 8 females, 4 males, 18–29 years old). All of the participants reported normal or corrected-to-normal vision, no history of motor or neurological impairments. All participants, except for two, were right-handed. All participants used their preferred hand in the testing and training phases of the study.

2.2 Ethics Statement

This study was approved by the Institutional Review Board at IU Bloomington and all participants gave written informed consent.

2.3 Apparatus

Participants interacted with a 3D display by moving a handheld stylus with their dominant hand/arm. The display was presented on a 15" computer screen that was located on a desk 70cm from participants. The stylus was attached to a desktop force feedback haptic virtual reality device, a PHANTOM Omni (Sensable Technologies, Inc.) and was located 50cm in front and 10 cm to the right (or left for left-handed participants) of the computer screen. The PHANTOM is an impedance control device (Hogan, 1985) where the user moves the stylus and the device reacts with a force if a virtual object is encountered (the PHANTOM thus has displacement as an input and force as an output). The mass and friction of the actual PHANTOM has been made small by careful mechanical design using cables driven by high performance DC motors.

In all trials, a force was programmed so that the stylus was attracted to the path if it moved away from the 3D spatial locations that specified the path (at a phenomenological level as if a 'magnetic' force were present). The force pulling the stylus was modeled as a virtual spring where the stiffness of the spring could be altered. The spring had a virtual length of ≈ 0.5 cm from the center of the path so the force dropped to zero if the (virtual) stylus moved > 0.5 cm from the (virtual) path. The spring stiffness was parametrically varied to alter task difficulty. The forces pulling the stylus towards the spring were set at six different levels corresponding to forces of approximately 2.02N, 1.08 N, 0.83 N, 0.57N, 0.35N and 0.13N.

2.4 Procedure

All participants performed the same basic 3D tracing tasks during two sessions (baseline and post-training) separated by one to two weeks. The separation varied slightly across participants as it depended upon the availability of the participants (i.e. when it was convenient for them to attend for testing) but there were no group differences in the average time between sessions. Once centered with respect to the computer screen, participants were instructed to grasp the PHANTOM stylus as if they were grasping a pencil. The task was to use the PHANTOM to move a virtual stylus and control its endpoint to push a virtual red bead along a virtual 3D path visible in a computer graphics display (see Figure 1a) from a starting location (the solid square) to a finish location (the checkered square). Participants were asked to push the bead, from the starting location to the finish point, as quickly as possible. If participants deviated from the path, they had to return the stylus to the path at the location along the path where they had left it to continue pushing the bead to the finish point. This was explained to them. They were given no other explicit goals regarding accuracy. Trials ended either when the bead reached the finish point or 90 seconds had elapsed from the start of the trial ($< 0.05\%$ of all trials). The task was modeled on a wooden maze toy. The toy is commonly found in pediatrician waiting rooms consisting of colored beads on roller coaster like colored wires attached to a wooden base. The goal is to move a brightly colored bead from one end, through a series of twists and turns, to the other end. However, instead of being able to use one's fingers directly, a stylus must be used to move the bead along the wire path.

During the first session, participants performed two trials at each of six levels of support (12 total trials) on the Baseline Path (113cm in length, pictured in Figure 1a). The order of trials was fixed so that participants started with the highest level of support and progressed to the lowest. In order, spring stiffness values associated with the highest to lowest levels of support were: 2.02N, 1.08 N, 0.83 N, 0.57N, 0.35N and 0.13N. These stiffness values (and associated levels of support) correspond to variations in task difficulty and have been used in previous research (see Snapp-Childs et al., 2013b). Before one has acquired skill in performing this task, it is an extremely difficult task that elicits much frustration when attempted without any support, that is, with low stiffness. On the other hand, the goal of the task is to be able to move the bead from one end of the wire to the other end rapidly without any support.

After the baseline session, there were three training sessions that were completed on separate days. In the training sessions, participants in all three groups received training on a different set of paths (see Figures 1b, 1c, 1d; in order, paths were 84cm, 107cm, and 116cm in length). There were three training sessions. For the progressive training group, in each training session, participants performed two trials per path for each of six support levels (the same levels as in the baseline and post-training assessments) in a fixed order (36 training trials). For the moderate and low support training groups, in each training session, participants performed two trials per path in a fixed order (36 training trials); however, the level of support was fixed at a force of approximately 0.7N (moderate support group) or 0.24N (low support group). In all cases, the participants were asked to push the bead, from the starting location to the finish point, as quickly as possible.

After training, all participants completed a post-training session. During this session, participants performed the same set of trials as during the baseline session, plus an additional two trials on each of two novel paths at the lowest level of support (16 total trials). The novel paths are referred to as Transfer Paths (Transfer Path 1: 131cm in length; Transfer Path 2: 124cm in length) and are depicted in Figures 1e and 1f, respectively, and were fixed in order of presentation for all participants. These paths were chosen because they were longer paths with more extensive changes in curvature and torsion when compared to baseline – that is, they were more challenging. Performance on these paths allowed us to examine generalization of learning to more difficult conditions.

2.5 Data Analysis

The three dimensional Cartesian coordinates of the virtual stylus tip (corresponding to the red bead visible to the participants) were recorded at 50 Hz. These data were filtered using a dual pass second order Butterworth filter with a 5 Hz cut-off frequency. Using these data with the known coordinates of the target trajectory (the path) we computed both *temporal* and *spatial* measures of performance. Trial duration was computed as a temporal measure. Trial duration was the time it took for a trial to be completed (the time in seconds from when participants arrived at the starting location to when they arrived at the finish marker). We selected duration because it provides a single unambiguous global measure of performance that related directly to the explicitly stated goal of the task. Moreover, duration is typically used as a performance measure in a wide range of motor tasks (Weightman et al., 2011). We also examined two *spatial* kinematic performance measures both of which reflected positional error: frequency off path and normed path length. Especially with low spring stiffness, participants tended to come off the path and this cost time (the time required to re-position the stylus). Frequency off path was simply the number of times per trial that this happened (from when participants arrived at the starting location to when they arrived at the finish marker). Normed path length was the total distance travelled (in cm) in a trial by the participant controlled stylus (from when participants arrived at the starting location to when they arrived at the finish marker) divided by the actual wire path length.

We averaged the dependent measures separately for each participant, over the trials performed in a given condition (level of spring stiffness, path) and session (baseline versus post-training). Statistical analyses of the group differences and changes in the dependent measures were performed with mixed design and single factor analysis of variance. For these analyses, group (progressive support, medium level support, low support) was a between-subjects factor; support level (that is, level of spring stiffness which varied from 0.13N to 2.2N), session (baseline vs. post-training), and path (Baseline path vs. Transfer paths) were within-subjects factors. Training data was analyzed with group and training session (1–3) as between- and within-subjects factors respectively. The significance levels were set at $\alpha = 0.05$. We tested for violations of normality throughout and reported Greenhouse-Geisser adjusted p-values where sphericity was violated. Additionally, we report effect size (η^2) values. Regression analyses were also performed to examine the relationship between the temporal and spatial measures.

3. RESULTS

3.1 Temporal measure

We recorded the durations for completion of movements tracing these 3D wire paths. First, we confirmed that there were no differences among the groups tested before training. We performed a mixed design ANOVA on durations at baseline with group as a between-subjects factor and support level as within-subjects. Group was not significant ($p > 0.5$), nor was the interaction ($p > 0.4$). Support level was significant ($F(5, 165) = 61.7, p < 0.001; \eta^2 = 0.45$). As shown in Figure 2a, durations increased as the strength of the support decreased.

Next, we tested whether learning occurred. We computed a mean duration for each participant in each session (baseline and post training) and performed a mixed design ANOVA with session as within-subjects factor and group as a between-subjects factor. There was only a significant main effect of session ($F(1, 33) = 99.1, p < 0.001; \eta^2 = 0.49$). As shown in Figure 3, durations were smaller in the post-training session.

Next, we investigated differences between groups post-training. We performed a mixed design ANOVA on post-training durations with group as a between-subjects factor and support level as a within-subjects factor. There was a significant main effect of support level ($F(5, 165) = 66.2, p < 0.001; \eta^2 = 0.52$) and a significant group by support level interaction ($F(10, 165) = 4.4, \text{adjusted-}p < 0.005; \eta^2 = 0.07$). We performed post hoc Tukey HSD tests to investigate the interaction. We found significant differences between groups only at support level 6 (low support) where the medium level support group was different from both the progressive support and low support groups ($p < 0.001$). The progressive support and low support groups were not different from one another. As shown in Figure 2a, duration at support level 6 was greater for the single level support group than for the other two groups.

Finally, we tested group differences of durations for the transfer paths. A factorial ANOVA yielded a significant main effect for group ($F(2, 33) = 3.9, p < 0.03; \eta^2 = 0.10$). We performed t-tests (2-tailed) on the groups taken two at a time. The medium level support group was different from both the progressive support group ($t(22) = -2.16, p < 0.05$) and the low support group ($t(22) = 2.20, p < 0.04$), but the latter two groups were not different from one another ($p > 0.9$). Durations for the medium level support group were longer than for the other two groups. The mean durations were 24.9 s for the progressive support group, 31.8 s for the medium level support group, and 24.8 s for the low support group.

3.2 Spatial measures

We recorded two spatial measures, the normed path length and the frequency off path. These were each treated to the same set of analyses as the durations.

3.2.1 Normed path length—The ANOVA on normed path lengths in baseline yielded a significant main effect for support level ($F(5, 165) = 33.0, p < 0.001; \eta^2 = 0.34$), but group ($p > 0.7$) and the interaction ($p > 0.9$) were not significant. As shown in Figure 2, normed path lengths increased as the strength of support decreased. The ANOVA comparing normed path lengths in baseline versus post-training yielded only a significant main effect of session ($F(1, 33) = 31.2, p < 0.001; \eta^2 = 0.24$). As shown in Figure 2b, normed path lengths

decreased over sessions for all groups. The ANOVA on normed path lengths in post-training yielded significant main effects of group ($F(2, 33) = 6.7, p < 0.01$), support level ($F(5, 165) = 42.4, p < 0.001$) as well as a significant interaction ($F(10, 165) = 3.6, \text{adjusted-}p < 0.01$). We performed post hoc Tukey HSD tests to investigate differences among groups in the interaction and found that the progressive support and medium level support groups were different at support level 6 ($p < 0.001$) and the medium level support and low support groups were different at support levels 5 and 6 ($p < 0.01$), but the progressive support and low support groups were not different at any support level. As shown in Figure 2b, normed path lengths increased as the strength of support decreased. The normed path lengths for the medium level support group were larger at support level 6 than for the other two groups.

Then, we tested group differences for normed path lengths in transfer trials. The ANOVA was significant ($F(2, 33) = 11.4, p < 0.001$). Post hoc t-tests (2-tailed) showed that the medium support level group was different from the progressive support group ($t(22) = 3.34, p < 0.01$) and the low support group ($t(22) = 3.9, p < 0.001$), but the latter two groups were not different from one another ($p > 0.4$). The mean normed path lengths were 1.53 for the progressive support group, 2.10 for the medium level support group, and 1.46 for the low support group.

3.2.2 Frequency off path—The ANOVA on frequency off path in baseline yielded a significant main effect only for support level ($F(5, 165) = 55.8, p < 0.001$). As shown in Figure 2c, frequency off path increased as the strength of support decreased. The ANOVA comparing frequency off path in baseline versus post-training yielded only a significant main effect of session ($F(1, 33) = 33.7, p < 0.001$). As shown in Figure 2c, frequency off path decreased over sessions for all groups. The ANOVA on frequency off path in posttraining yielded significant main effects of group ($F(2, 33) = 4.8, p < 0.02$), support level ($F(5, 165) = 57.4, p < 0.001$) as well as a significant interaction ($F(10, 165) = 5.3, \text{adjusted-}p < 0.005$). We performed post hoc Tukey HSD tests to investigate group differences in the interaction and found that the medium level support group was different at support level 6 from both the progressive support ($p < 0.05$) and the low support ($p < 0.05$) groups, but the progressive support and low support groups were not different at any support level. As shown in Figure 2c, the frequency off path increased as the strength of support decreased. The frequency off path for the medium level support group was larger at support level 6 than for the other two groups.

We tested group differences for frequency off path in transfer trials. The ANOVA was significant ($F(2, 33) = 4.7, p < 0.02$). Post hoc t-tests (2-tailed) showed that the medium support level group was different from the progressive support group ($t(22) = 2.3, p < 0.03$) and the low support group ($t(22) = 2.4, p < 0.03$), but the latter two groups were not different from one another ($p > 0.8$). The mean frequency off path were 6.71 for the progressive support group, 11.10 for the medium level support group, and 6.54 for the low support group.

3.3 Relation between temporal and spatial measures

Finally, we analyzed the relation between frequency off path and duration to determine whether learning and improved performance affected either the time to return to the path after the stylus had come off it or the time to move along the path while in contact with it. We regressed frequency off path on duration. The slope of the resulting fitted linear relation measured the average time to return to the path while the intercept measured the time to traverse the entire path while in contact with it. We performed multiple regressions comparing the three support groups taken two at a time to test differences in slope and intercept (Pedhazur, 1982). When we performed these latter analyses on baseline data, we found no differences among the groups. A simple regression on the combined data at baseline was significant ($F(1, 214) = 1756.9$, $p < 0.001$, $r^2 = 0.89$) yielding a slope of 2.13 and an intercept of 13.1. So, before training, traversing the path without coming off of it took, on average, 13.1 seconds and the time to return to the path each time the stylus came off it was 2.13 seconds.

Next, we compared the groups at post-training. A comparison of progressive support and low support groups was significant ($F(3, 140) = 166.3$, $p < 0.001$, $r^2 = 0.78$). The intercepts were significantly different ($t = 2.1$, $p < 0.05$), but not the slopes. A comparison of the medium support and low support groups was significant ($F(3, 140) = 273.5$, $p < 0.001$, $r^2 = 0.85$). The intercepts were significantly different ($t = 2.9$, $p < 0.005$), but the slopes were not. Finally, a comparison of the progressive support and medium support groups was significant ($F(3, 140) = 368.6$, $p < 0.001$, $r^2 = 0.89$), but neither the intercepts nor the slopes were different. For the combined groups (since they were not different in respect to slope), the slope was 2.04 seconds. The intercept for the combination of the progressive and medium support groups (since they were not different) was 7.26 seconds. The intercept for the low support group (that was different from the other two groups) was 8.48 seconds. Thus, after training, the time to return the stylus to the wire path was still about 2 seconds for all groups. The time to traverse the path while remaining in contact with it was 7.26 seconds (improvement of 5.86 seconds) for the progressive support and medium support groups and 8.48 seconds (improvement of 4.62 seconds) for the low support group.

3.4 Training data

We analysed durations recorded during the three training sessions with the expectation that durations would be greater without magnetic support. We performed a mixed design ANOVA on durations with group as a between-subjects factor and training session as a repeated measures factor. This yielded main effects for group ($F(2, 33) = 23.0$, $p < 0.001$) and for training session ($F(2, 66) = 136.1$, $p < 0.001$) as well as an interaction ($F(4, 66) = 11.6$, $p < 0.001$). As shown in Figure 3a, durations for the low support group were greater than for both of the other two groups that were not different from one another. Sheffe tests comparing among the group means showed that the low support group was different from the progressive support group and from the medium support group ($p < 0.001$), but the progressive support group and medium support group were not different from one another. On the other hand, all sessions of training were different from one another for the low support group ($p < 0.05$) while only the first session was different ($p < 0.05$) from the other

two for the progressive support and medium support groups. To keep performance level approximately constant (and duration relatively low) was a goal of progressive support.

We tested frequency off path in the same way as duration. The result again yielded main effects for group ($F(2, 33) = 6.1, p < 0.01$) and for training session ($F(2, 66) = 27.8, p < 0.001$) as well as an interaction ($F(4, 66) = 5.8, \text{adjusted-}p < 0.005$). As shown in Figure 3b, frequency off path for the low support group was greater than for the other two groups that were not different from one another. Tukey HSD tests showed that low support was different ($p < 0.001$) from progressive and medium support, while the latter two were not different from one another, at each training session except the third where none were different from the others. The differences among training sessions within each group were the same as for durations, that is, all were different ($p < 0.05$) for low support, but only session 1 was different ($p < 0.05$) from each of the other two sessions for progressive and medium support groups.

In sum, during training, the low support group produced longer durations and larger frequencies of times off than for either the progressive or the medium support groups, especially earlier in training.

4. Discussion

The goal of the current study was to determine how variations in practice structure affect the efficacy of motor learning – can practice with a single level of support yield performance improvements equivalent to those yielded by the regimen of progressively modulated support? In sum, the answer is *yes* but only if the support is sufficiently low: the progressive support group performed better at post-test than did the medium level support group and the low support group learned to perform equally well post-training as did the progressive support group. Also, as had Snapp-Childs et al. (2013a), we performed an analysis to determine where the improvement was occurring. Were participants learning to return more rapidly to the 3D wire path when they came off it in error or were they, instead, learning to control their movement along the 3D path more effectively (presumably by improving their prospective control, learning to anticipate the twists and turns in the path)? The results replicated the previous finding that the time to get back onto the path did not change while the time taken to move along the path did. They learned to control their movement along the path better and got faster. As a result, they also incurred less error, coming off the path less often. To be able to do this well without support in the end, however, they had to practice without support. While these findings were very clear, we do not believe that practicing exclusively under the most difficult conditions is a good choice for a training regime. This is because the low support group suffered from much poorer performance during the training. Thus, the key to the best post-training performance was specificity of training. On the other hand, modulated support yielded better performance during training and thus, potentially better self-efficacy.

What was being learned?

The support provided in this study was a form of ‘corrective assistance’ where a spring-force held the user-controlled stylus onto the 3D path. This spring-force was experienced as

‘magnetic attraction’ that allowed the user to focus on producing movement strictly along the targeted 3D path. The best strategy for performing the resulting task was to move in a compliant manner while looking ahead to anticipate curves in the wire to allow the wire to guide the movement. Training on the 3D path enabled improved kinesthetic sensitivity to the path as a constraint surface and visual sensitivity to the shape of the path. These, aspects, in turn led to better compliance control and better prospective control. However, of course, the training regime dictated the level of improvement on those aspects. We analyzed the temporal and spatial characteristics of performance to reveal the specific nature of the improvement in performance. In all cases, participants improved in their continuous control of the stylus moving along the required path so as to reduce the frequency with which they deviated from the target path. As in our previous work (e.g. Snapp-Childs et al., 2013a), we found that reduced trial durations were not produced by quicker return to the target path. Rather, the participants exhibited improved prospective control that better anticipated the path (its 3D curvature and torsion) so as to successfully maintain contact with and follow that path and avoid costly departures from the target path. As before, (active) training yielded progressive improvements in prospective control and thus, effective sensorimotor learning. However, we also found that training exclusively under low support conditions fostered a more conservative approach. While this strategy is very effective for healthy, young adults it may not be for individuals with motor impairments or difficulties due to additional internal (organism) constraints.

Extensions to special populations

These findings are important for the design of training protocols for use with robotic systems that are being developed to improve upper limb function for individuals with motor impairments such as children with Developmental Coordination Disorder or adults after stroke. For example, Snapp-Childs et al. (2013b) developed a method of training good compliance control in manual actions involving manipulation of a stylus (pen or pencil) in contact with a surface. The goal was to improve drawing and handwriting performance by children with Developmental Coordination Disorder. The method required the performer to generate and control the manual actions actively while nevertheless receiving support that would allow all performers to succeed well in the task and thus experience good self-efficacy. The approach was shown to yield good learning and improvement in subsequent post-training performance with low support (Snapp-Childs et al., 2013a; Snapp-Childs et al., 2013b; Snapp-Childs et al., 2014). Children with Developmental Coordination Disorder, for whom the task was initially impossible without support, became able to perform as well without support as did typically developing children who had also trained at the task. However, it was possible that this training regimen is un-necessarily complex. While some learners require support to aid control of their movements during training, it was possible that a single moderate (medium) level of support might suffice. Thus, it was not clear how specific should the training be.

The objective is to allow learners to eventually perform well in the task with low support. Is it therefore important to provide training that includes low support? The findings from the current study indicate that training with progressive reduction of support is optimal for two reasons: 1) it allows for the best learning and 2) the difficulty during practice sessions tracks

the learner's performance level and thus potentially promotes good self-efficacy during training. As for the first aspect, on the one hand it is not particularly surprising that the progressive support yielded good learning – that training regime contained trials with low support. Again, according to the practice specificity hypothesis (Proteau, 1992), the best learning outcomes are produced when practice and testing conditions are highly similar. On the other hand, though, the low support training regime exclusively utilized low support trials; thus, more training was performed under those conditions; yet, the learning under those conditions was not superior to the learning occurring with progressive training – this would appear to contradict the practice specificity hypothesis.

We believe that this second aspect is particularly important. It means that disadvantaged performers can “get into the game” and are more likely to continue participating in the training. This may be especially important for individuals who are predisposed towards lower self-efficacy with respect to motor skills or physical activity. For instance, children with Developmental Coordination Disorder have been shown to be less likely to be physically active than their typically developing peers and to have lower levels of self-efficacy for physical activity (Cairney et al., 2005; Cairney et al., 2010). Although the relationship between (motor skill) activity participation and self-efficacy for such activities is undoubtedly complex, one avenue to increasing or promoting participation may be through improving self-efficacy via training programs such as the one that we have developed.

Conclusions

We conclude that progressive modulation of support during training is required for effective training of for two reasons. Modulated support during training is required, first, to reduce training difficulty and potentially preserve good self-efficacy and, second, to yield effective learning given the specificity of training.

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HIGHLIGHTS

- We examine whether the progressive modulation and reduction of support during training was required to yield good performance after training without support.
- Training exclusively with medium support yielded post-training performance that was not as good as that yielded by training with progressive reduction of support.
- Training exclusively with low support yielded post-training performance that was equally good as that yielded by training with progressive reduction of support.
- Performance during training with low support was worse than when training with progressive modulation of support or medium support.
- Thus, less support during training yields effective learning but more difficult training sessions.

Figure 1.

A) The PHANTOM Omni with the display illustrating the path used in baseline and posttest trials; B), C), D) Illustration of the paths used in training in the 3D tracing task; E), F) Transfer paths.

Figure 2.

For each session, support level, and training group: A) Mean duration, B) Mean normed path length, C) Mean number of times off path. Error bars are standard errors. At Baseline, the groups showed similar (poor) performance. After training, the progressive support and low support groups showed the best performance in the low support condition.

Figure 3.

During training, for each training group: A) Mean durations, B) Mean number of times off path. Error bars are standard errors. All groups improved during training. Overall, the medium support group showed the best overall performance followed by the progressive support training group; the low support group performed much worse than the other groups during training.