Motor learning in children with hemiplegic cerebral palsy: feedback effects on skill acquisition

Robin S. Leinwand

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MOTOR LEARNING IN CHILDREN WITH HEMIPLEGIC CEREBRAL PALSY: FEEDBACK EFFECTS ON SKILL ACQUISITION

by

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THESIS

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ABSTRACT

Purpose. Augmented feedback is an important variable influencing motor learning. Previous studies show reduced feedback frequency benefits motor learning in young adults more than a comparison group of children, who benefit from frequent feedback during practice. It is unclear how motor and central nervous system differences in children with cerebral palsy may impact their use of feedback in motor skill acquisition. This study investigated the effect of augmented visual feedback (FB) on performance and learning of an upper extremity motor skill in children with spastic hemiplegic cerebral palsy (SHCP) as they practiced with their less affected arm, compared to typically developing children (TDC).

Methods. Participants were 8-17 years with academic performance within two grade levels. Both TDC (n = 20) and participants with SHCP (n = 19) were screened for visual perception (MVPT-3) and manual dexterity (Box and Block). Children were divided into groups receiving frequent FB (100%) or faded FB
(62%). Group differences for acquisition, retention, and reacquisition were compared in relation to FB level.

**Results.** Both groups of children used visual FB to improve motor performance during skill practice. All children receiving 62% FB performed with greater error than children receiving 100% FB during the acquisition phase ($p = .012$), delayed retention no-feedback test ($p = .017$), and reacquisition phase ($p = .042$). Children with SHCP in both FB groups performed with significantly greater error than TDC during the entire acquisition phase ($p < .001$), delayed retention no-feedback test ($p = .031$) and reacquisition phase ($p = .001$). While no significant within group feedback effect was found for children with SHCP, there was a trend for greater accuracy in the 100% group as compared to the 62% group during acquisition ($p = .092$) and this trend was seen again during reacquisition when FB was reintroduced ($p = .092$).

**Conclusions.** Results suggest that for children with SHCP skill acquisition is furthered by visual FB regarding their movement accuracy. Children with SHCP use visual FB in a manner similar to TDC, although differences in learning were evident during the acquisition, delayed retention, and reacquisition phases. Further investigation is needed to determine clinical implications.
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Chapter 1
Introduction

Cerebral palsy (CP) is a common childhood disorder beginning early in life and impacting multiple areas of development. Most notable are motor deficits that interfere with functional tasks and mobility, although various cognitive and sensory deficits are frequently associated (Batshaw, Pellegrino, & Roizen, 2007; Rosenbaum et al., 2007). The impairments, activity limitations, and accompanying disturbances may be directly related or secondary to functional changes over time (Rosenbaum et al., 2007).

CP occurs in approximately 2.0-2.5:1000 live births within the general population (Batshaw et al., 2007). This rate has remained fairly consistent over the past 50 years. It is generally understood that the incidence of CP increases as birth weight and gestational age decrease (Cans, De-la-Cruz, & Mermet, 2008; Krageloh-Mann & Cans, 2009). Recent publications report .33 -.43% of children 3-17 years old in the U.S. are diagnosed with CP (Boyle et al., 2011; Kirby et al., 2011). Also of interest is the difference between prevalence among children living < 200% poverty level (.41%) and those living > 200% poverty level (.34%) (Boyle et al., 2011). Prevalence was noted to be markedly lower for Hispanic children (.22%) (Kirby et al., 2011).

CP is one of the most common causes of physical disability in early childhood (Krageloh-Mann & Cans, 2009) and children with CP constitute the largest clinical group seen in pediatric occupational therapy (Novak, Cusick, & Lannin, 2009). Spastic CP, the most common type, represents approximately
85% of cases and involves injury to the cortex and pyramidal tracts resulting in excess muscle tone or spasticity (Batshaw et al., 2007; Kirby et al., 2011; Krageloh-Mann & Cans, 2009; Reid, Carlin, & Reddihough, 2011; Towsley, Shevell, Dagenais, & Consortium, 2011). Individual manifestations are further characterized by body/limb distribution and include hemiplegia, diplegia, and quadriplegia.

**Impairments in Cerebral Palsy**

It is generally agreed that all individuals with CP have problems with movement and posture (Batshaw et al., 2007), but the diversity that exists across individuals must be recognized. Specific impairments result from lesion location, amount of damage, and stage of brain development at the time of injury.

Spastic hemiplegia impacts one side of the body more than the other, with the arm typically more involved than the leg. The involved side is contralateral to the area of brain affected (Batshaw et al., 2007). Hemiplegia is often accompanied by a certain level of involvement on the less affected side impacting both motor execution and motor planning (Janssen & Steenbergen, 2011; Steenbergen, 2006). Findings of decreased hand skill performance and speed (Dellatolas, Filho, Souza, Nunes, & Braga, 2005), motor planning deficits specific to object manipulation (Steenbergen, Verrel, & Gordon, 2007), and delayed development of motor planning (Janssen & Steenbergen, 2011) have been reported. Involvement on the less affected side complicates accurate classification (Blair, 2010; Rethlefsen, Ryan, & Kay, 2010; Rosenbaum et al., 2007).
In addition to movement and motor control difficulties, CNS damage in children with spastic hemiplegia may result in a variety of associated impairments (Batshaw et al., 2007). The most common of these are difficulties connected to cognition, learning, and sensation (Batshaw et al., 2007). Consistent positive correlations between the number and degree of associated impairments and severity of motor difficulties have been found (Batshaw et al., 2007; Himpens, Van den Broeck, Oostra, Calders, & Vanhaesebrouck, 2008; da Costa, Salomão, Berezovsky, de Haro, & Ventura, 2004). Difficulties/differences in visual perception are thought to be a contributing factor (Burtner, Dukeminier, Ben, Qualls, & Scott, 2006; Tsai, Lin, Liao, & Hsieh, 2009).

The combined effect of motor and associated impairments is correlated with activity limitations and an increased need for health care services and intervention to support both the individual and their family (Boulet, Boyle, & Schieve, 2009; Boyle et al., 2011; Cans et al., 2008; Mutlu, Akmese, Gunel, Karahan, & Livanelioglu, 2010). A recent study of long-term outcomes of CP indicates the impact of impairments strongly influences an individual's functional activity, leisure participation and quality of life far beyond the childhood years (Mesterman et al., 2010). An understanding of the needs of each child related to their clinical presentation allows professionals to plan appropriate intervention for maximum function and participation.

**Motor Learning in Children with Cerebral Palsy**

As CP is considered a condition primarily impacting motor control and movement, motor learning is an important focus of research. Motor learning
research studies the acquisition or modification of movement with the goal of developing skilled movements or actions (Shumway-Cook & Woollacott, 2012). Effective motor learning is thought to primarily depend upon the practice parameters and feedback conditions in place during the learning.

Children with CP are able to improve motor function with time and practice. Studies have shown that motor learning may be a slower process, but extended practice leads to improvement in grasp/object manipulation, in hand manipulation, and postural control. Functional and task oriented treatment approaches have the potential for improving motor function when implemented with adequate intensity (Gordon & Magill, 2011).

Numerous studies have shown that reduced feedback frequency during practice benefits motor learning in adults, but information regarding how feedback frequency and type impact skill acquisition for children is sparse. While the role of feedback to facilitate goal attainment and provide motivation is likely similar, differences in how children use information for learning might impact precisely how this occurs. Fitts and Posner describe a three-stage model of motor learning (Shumway-Cook & Woollacott, 2012) that can inform the role of cognitive effort during skill acquisition. In the first stage, the learner is focused on understanding the task and determining the most effective way to meet the goal. This is referred to as “the cognitive stage” due to the high degree of attention and cognitive effort required. As many strategies are usually tried, performance is typically inconsistent in this stage of learning. Even so, the most dramatic skill improvement usually occurs during this phase (Schmidt & Lee, 2011).
learner moves into the second, or “associative”, stage, once an effective strategy has been chosen. Performance improves much more slowly as small changes are made for skill refinement. The third stage is “the autonomous stage”. At this point practice is no longer necessary and the learner performs the skill essentially “automatically”. Markedly less cognitive effort is required and the individual can attend to task aspects beyond the movement pattern required (Schmidt & Lee, 2011; Shumway-Cook & Woollacott, 2012).

Less frequent FB would seem beneficial, particularly during the initial stage of learning, so as not to overload a child’s less capable information processing system. Findings of a 2008 study indicate otherwise. Important differences between adults and typically developing children in the use of augmented feedback for motor skill acquisition were demonstrated (Sullivan, Kantak, & Burtner, 2008). In contrast to previous understandings, typically developing children demonstrated better learning when frequent feedback was provided during practice (Sullivan et al., 2008).

**Purpose of Current Study**

It is unclear how motor and central nervous system differences in children with cerebral palsy may impact their use of feedback in their motor skill acquisition. Due to a lack of well-designed motor learning studies in children with or without CP, therapists must rely on principles of motor learning derived from healthy young adults and generalize these findings to children. For occupational therapy practitioners to offer the most effective interventions to clients, methods must be defined, described, and tested, so practitioners know what has been
determined most useful for individuals with specific conditions (AOTA, 2009). The purpose of this study was to investigate the effect of visual feedback on performance and learning of a motor skill involving the less affected arm in children with spastic hemiplegic cerebral palsy (SHCP) compared to typically developing children (TDC). Taking into account what is known about how children use feedback and possible learning differences for children with SHCP, two specific hypotheses exist. First, it is hypothesized that, during acquisition and retention phases, children with CP will have more error than a control group of typically developing children. Second, it is anticipated that, during both acquisition and retention phases, children with CP who receive feedback after every practice trial (100%) will have less movement error than those who receive reduced feedback frequency (62% feedback) during practice.
Chapter 2
Methods

Participants

A total of 39 children voluntarily participated in the study. Nineteen children with a diagnosis of spastic hemiplegic cerebral palsy (9 male, 10 female; mean age = 11.6 years, SD = 2.3, range = 8-16) were recruited from the metropolitan area of Albuquerque, New Mexico. Inclusion criteria for this group were: between the ages of 8 and 17 years, a diagnosis of spastic hemiplegic cerebral palsy, and academic performance within two years of grade level expectations. Grade level performance was determined by parent report and confirmed by referring therapists familiar with the children’s current academic progress. Twenty typically developing children (12 male, 8 female; mean age = 10.7 years, SD = 2.0, range = 8–14) were recruited from the greater Los Angeles area. Inclusion criteria for this group of children were between the ages 8 and 14 years who were developing typically, and performing at grade level in school. All children demonstrated attention as required to follow protocols. Exclusion criteria for all participants were any orthopedic or neurological problems that would interfere with the ability to perform a coordinated arm movement. Five children with CP were excluded due to an incorrect CP subtype diagnosis, a non-congenital CP diagnosis, or academic performance outside of inclusion criteria. One additional child with CP completed the study protocol, but was later excluded. Analysis revealed deterioration of performance with practice, suggesting the subject was not representative of the group in general, hence an
outlier. Approval was obtained from the Human Research Review Board at both 
the University of Southern California and the University of New Mexico. Prior to 
study involvement, the experimental protocol and time commitment was 
explained to both children and parents. Upon agreement to participate, child 
assent and parental consent were obtained.

Participant demographics and baseline information was gathered prior to 
completion of the computer protocol and clinical measures. CP group 
demographics for handedness, age, gender, medical history, and MACS level 
(Eliasson et al., 2006) by parent report are presented in Table 1. Additional 
demographic information from parent report indicates that, among all participants 
with SHCP (n = 19), 11 had delayed independent walking, eight had delayed 
speech, 14 were in a regular education classroom placement, four receive 
special education support in addition to regular education for academic success, 
and two qualified for gifted education services. As all children met defined 
inclusion criteria, these details are provided as background information.
### Table 1

**Participant Demographics**

<table>
<thead>
<tr>
<th>Participant</th>
<th>Feedback Condition</th>
<th>Age</th>
<th>Gender</th>
<th>Diagnosis</th>
<th>Clinical History</th>
<th>MACS level</th>
<th>Vision</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100%</td>
<td>12</td>
<td>M</td>
<td>LH</td>
<td>term delivery, ADD, regular ed</td>
<td>II</td>
<td>WNL</td>
</tr>
<tr>
<td>2</td>
<td>100%</td>
<td>8</td>
<td>M</td>
<td>RH</td>
<td>term delivery, BTX, regular/gifted ed</td>
<td>II</td>
<td>WNL</td>
</tr>
<tr>
<td>3</td>
<td>100%</td>
<td>11</td>
<td>F</td>
<td>RH</td>
<td>term delivery, BTX, ADHD, regular ed</td>
<td>II</td>
<td>WNL</td>
</tr>
<tr>
<td>4</td>
<td>100%</td>
<td>11</td>
<td>F</td>
<td>LH</td>
<td>term delivery, BTX, regular ed</td>
<td>II</td>
<td>WNL</td>
</tr>
<tr>
<td>5</td>
<td>100%</td>
<td>9</td>
<td>F</td>
<td>RH</td>
<td>term delivery, regular ed</td>
<td>II</td>
<td>WNL</td>
</tr>
<tr>
<td>6</td>
<td>100%</td>
<td>12</td>
<td>M</td>
<td>RH</td>
<td>preterm delivery (27w), regular ed</td>
<td>II</td>
<td>C</td>
</tr>
<tr>
<td>7</td>
<td>100%</td>
<td>10</td>
<td>M</td>
<td>RH</td>
<td>term delivery, BTX, regular/special ed</td>
<td>II</td>
<td>WNL</td>
</tr>
<tr>
<td>8</td>
<td>100%</td>
<td>12</td>
<td>M</td>
<td>RH</td>
<td>term delivery, regular ed</td>
<td>I</td>
<td>WNL</td>
</tr>
<tr>
<td>9</td>
<td>100%</td>
<td>8</td>
<td>F</td>
<td>LH</td>
<td>term delivery, regular ed</td>
<td>II</td>
<td>WNL</td>
</tr>
<tr>
<td>10</td>
<td>62%</td>
<td>16</td>
<td>M</td>
<td>RH</td>
<td>term delivery, BTX, regular ed</td>
<td>II</td>
<td>WNL</td>
</tr>
<tr>
<td>11</td>
<td>62%</td>
<td>9</td>
<td>F</td>
<td>RH</td>
<td>term delivery, regular ed</td>
<td>II</td>
<td>WNL</td>
</tr>
<tr>
<td>12</td>
<td>62%</td>
<td>11</td>
<td>M</td>
<td>LH</td>
<td>unknown delivery, regular/special ed</td>
<td>III</td>
<td>WNL</td>
</tr>
<tr>
<td>13</td>
<td>62%</td>
<td>15</td>
<td>F</td>
<td>RH</td>
<td>term delivery, BTX, regular ed</td>
<td>I</td>
<td>WNL</td>
</tr>
<tr>
<td>14</td>
<td>62%</td>
<td>10</td>
<td>M</td>
<td>RH</td>
<td>term delivery, ADHD, regular ed</td>
<td>I</td>
<td>WNL</td>
</tr>
<tr>
<td>15</td>
<td>62%</td>
<td>9</td>
<td>M</td>
<td>RH</td>
<td>term delivery, BTX, ADHD, regular ed</td>
<td>II</td>
<td>WFL</td>
</tr>
<tr>
<td>16</td>
<td>62%</td>
<td>11</td>
<td>F</td>
<td>RH</td>
<td>term delivery, BTX, regular/special ed</td>
<td>II</td>
<td>WNL</td>
</tr>
<tr>
<td>17</td>
<td>62%</td>
<td>11</td>
<td>F</td>
<td>RH</td>
<td>term delivery, BTX, regular/special ed</td>
<td>II</td>
<td>WFL</td>
</tr>
<tr>
<td>18</td>
<td>62%</td>
<td>11</td>
<td>F</td>
<td>LH</td>
<td>preterm delivery 26w regular/gifted ed</td>
<td>I</td>
<td>C</td>
</tr>
<tr>
<td>19</td>
<td>62%</td>
<td>15</td>
<td>F</td>
<td>RH</td>
<td>term delivery, regular ed</td>
<td>II</td>
<td>WNL</td>
</tr>
</tbody>
</table>

**Note.** All participants had hearing WNL.

*a* LH = left hemiplegia; RH = right hemiplegia. *b* BTX = botulinum toxin A, if indicated, participant had injections on hemiplegic UE; ADD = attention deficit disorder; ADHD = attention deficit hyperactivity disorder (controlled with medication, except participant 15). *c* Manual Abilities Classification System (Eliasson et al., 2006). Level I = handles objects easily and successfully; level II = handles most objects; level III = handles objects with difficulty, needs help to prepare and/or modify activities.

d*WNL = within normal limits; C = corrected vision worn during tasks; WFL = no correction prescribed (participant 15, previous concerns resolved).
Clinical Measures

All participants were assessed for deficits in visual perception with the Motor-Free Visual Perception Test (MVPT-3). Gross manual dexterity was assessed using the Box and Block Test. A researcher trained and tested for reliability conducted all tests, with inter-rater reliability at or above 90% agreement.

*Motor-Free Visual Perception Test 3rd Ed (MVPT-3).* The MVPT-3 is a reliable and valid norm-referenced measure of overall visual perceptual processing ability in children and adults without the need for motor involvement (Colarusso & Hammill, 2003). The MVPT-3 assesses five aspects of visual perception such as visual memory and spatial relations that may affect visuomotor learning. Updated norms reflect a nationally representative sample of children and adults with no motor, sensory, or learning disabilities, with equal representation of genders, but limited in geographic representation. The test is not timed and requires approximately twenty-five minutes to administer. Raw scores are converted to perceptual quotients and perceptual ages. Reliability studies on the previous edition have shown high inter-rater and test-retest reliability quotients (Burtner, Ortega, Morris, Scott & Qualls, 2002) as well as reliability with children with CP (Auld, Boyd, Moseley, & Johnston, 2011; Tsai et al., 2009).

*Box and Block Test of Manual Dexterity.* The Box and Block test, often used by occupational therapists, was originally developed to evaluate the gross manual dexterity of adults with CP (Mathiowetz, Federman, & Wiemer, 1985).
The test is made up of a box with a partition directly in the center creating two equal sides. A number of 1 inch wooden cubes are placed in one side of the box. The subject uses the dominant hand to grasp one block at a time and transport it over the partition and release it into the opposite side. The subject is given 60 seconds in which to complete the test, and the number of blocks transported to the other side is counted. The test is then repeated with the non-dominant hand. Mathiowetz, Federman, and Wiemer (1985) developed normative values for children 6-19 years old and determined the Box and Block test well suited for both children and adults due to its’ short administration time and simple directions. Test-retest reliability was found to be ≥0.937 and inter-rater reliability to be ≥0.999 (Mathiowetz et al., 1985).

All children with CP were evaluated with the following additional measures for upper limb strength, visual-motor coordination, and visual perception on day 2.

*Grip Strength.* The Jamar grip dynamometer is an instrument used to measure hand strength. The standard protocol recommended by Mathiowetz, Weimer, and Federman (1986), used in their testing of 6-19 year olds, was followed in this study. Participants are seated with the shoulder adducted and neutrally rotated, elbow flexed at 90 degrees, with the forearm in neutral position, and the wrist between 0 and 30 degrees of dorsiflexion and between 0-15 degrees of ulnar deviation. The researcher demonstrated the task. After positioning the dynamometer in the participant’s hand, the researcher said, “Ready? Squeeze as hard as you can.” The participant squeezed three separate
times with each hand, alternating between the involved and non-involved arm, with rest periods given between attempts. The scores for each hand were averaged. Norms have been established for children as young as five. Interrater reliability was found to be >0.88 when using the method described above (Mathiowetz et al., 1986).

**Pinch Strength.** A pinch dynamometer measures finger grasp strength. The protocol outlined by Mathiowetz et al. (1985) describes the lateral (key) pinch as placing the thumb against the radial side of the index finger between the distal and proximal interphalangeal joint. The test is administered by first giving a demonstration and then saying, “Ready? Pinch as hard as you can.” The test is administered three times per session with a rest between each trial and an average of trials is recorded. Inter-rater reliability for the protocol was found to be 0.979 and test-retest reliability after one week >0.81 (Mathiowetz et al., 1986).

**Developmental Test of Visual-Motor Integration (VMI) 5th Ed.** The (Beery) VMI is a measure of the degree to which visual perception and motor behavior are integrated in children ages 2-15 years (Beery, Buktenica, & Beery, 2006). The test includes a series of 24 geometric forms developmentally sequenced in increasingly complex forms to be copied. Administration time is 10-15 minutes. The VMI test was selected for this study since this is a clinical tool most commonly used in the clinical setting by occupational and physical therapists. A predictive validity study reported by authors stated correct prediction of 85% of kindergarten children who had reading problems 7 years later (Burtner et al., 1997).
Two additional measures evaluating hand sensation were completed with 11 (of the 19) children with SHCP.

Two-Point Discrimination Test (2PD). The 2PD test was used to measure the ability to distinguish two closely placed point stimuli as two stimuli rather than one (Krumlinde-Sundholm & Eliasson, 2002). The test was performed with a Disk-Criminator touched to the pulp of the finger with either one prong or two, in a random pattern. Each finger was tested at least 5 times and no more than 10. Participants were first tested with a distance of 3mm. Five correct responses in a row indicates normal discrimination ability. If child was unable to differentiate one prong from two at this distance, a distance of 7mm was tried. For this test, each finger was tested and given a score of 2 points was given for five correct responses in a row, 1 point for slow or hesitant, but correct responses, and zero points for less than 5 correct responses in a row. Ten points total were possible for each hand. Krumlinde-Sundholm and Eliasson (2002) found the 2PD test at a distance of 3mm to be among the most useful and sensitive measures of tactile sensibility for children with hemiplegic CP. Use of the 2PD test with participants following nerve injury found test-retest reliability to be 0.96 (Dellon, Mackinnon, & Crosby, 1987) and inter-rater reliability to be 0.98 (Novak, Mackinnon, Williams, & Kelly, 1993).

Pick-Up Test. This test is a measure of functional sensibility requiring a combination of motor and sensory function in the hand. A modified protocol presented by Krumlinde-Sundholm and Eliasson (2002) was followed. Subjects moved 10 wooden cubes from a box to the table surface, one at a time, as
quickly as possible. The results were recorded in seconds. The task was completed first with the dominant hand and then with the non-dominant hand. Then the task was repeated without visual feedback. The authors noted that the time difference between completing this with vision and without addresses how an individual uses tactile /sensory information to guide motor actions.

**Computer Instrumentation and Task**

Participants from the Los Angeles area completed the computer task and clinical measures in the Motor Behavior and Neurorehabilitation Laboratory at the University of Southern California Los Angeles campus as part of a previous study (Sullivan et al., 2008). Participants from the greater Albuquerque area, including those with SHCP, completed the computer task and clinical measures at the University of New Mexico Health Sciences Center campus or at community locations including private homes and schools. When necessary, needs were accommodated with a mobile set up as pictured in Figure 3. The mobile set up consisted of the Los Angeles equipment used in the Albuquerque area. All researchers were trained to follow the same protocol described in the following section.

The motor task used in this study, described by Sullivan, Kantak, and Burtner (2008), was designed for participants to learn a discrete coordinated upper limb movement. Participants were seated in front of a computer monitor with their testing forearm resting on a lightweight horizontal lever arm in the front plane of the body, grasping the handle of the lever with their less involved (non-spastic) hand (see Figure 2). The movement was performed by producing two
elbow extension-flexion reversal movements in a horizontal plane (see Figure 1). A goal movement pattern was displayed on a computer monitor. Participants were instructed to move the lever to replicate the pattern on the screen. After the trial, the goal movement pattern (position-time trace) and the augmented visual feedback were displayed on the monitor. Feedback consisted of both an overall numeric error score (root mean square error [RMSE]) and a graphic representation of the participant’s response superimposed on the target movement pattern. For the no-feedback trials, the screen remained blank before the next trial began.

*Figure 1. Instrument set up.*

*Figure 2. Equipment and task set up in lab.*
Figure 3. Mobile equipment and task set up.

Figure 4. Child with mobile set up.
Figure 5. Goal movement line (red) and visual feedback presentation (blue line and RMSE number in top right corner).
Experimental Design

The computer based protocol included 2 phases: acquisition (day 1) and retention (day 2) (Sullivan et al., 2008). The acquisition phase consisted of four 50-trial practice sessions (200 total practice trials) with a 5-minute break between sessions. A 10-trial, no-feedback retention test was used as a reflection of the participant’s motor skill memory representation developed during practice. The retention test was followed by 20 trials with feedback to assess reacquisition performance. The reacquisition test is used as an additional test of motor memory and reflects the relative benefits of the previous day’s practice (i.e., whether the learner returned to the previous day’s baseline or not) and the learner’s ability to respond when additional practice trials are provided. Both retention and reacquisition tests have been used previously to assess motor learning (Winstein, Merians, & Sullivan, 1999).

All children were assigned to either a 100% feedback group ($n = 9$) or a reduced (62% faded) feedback group ($n = 10$). In the 100% feedback condition, children received augmented feedback after every trial throughout the entire acquisition phase. In the reduced feedback group, the relative frequency of feedback was progressively faded across four 50 trial sessions in the following manner: for session 1, relative feedback frequency was 100%; in session 2, the feedback frequency was reduced to 75%; in session 3, the feedback frequency was reduced to 50%; and in session 4, the feedback frequency was further reduced to 25%. Across the entire acquisition phase, participants in the faded
feedback group received a 62% frequency of feedback. The experimental design resulted in four experimental groups: (1) typically developing children who received 100% feedback, (2) children with SHCP who received 100% feedback, (3) typically developing children who received faded feedback, and (4) children with SHCP who received faded feedback.

**Computer Task Procedure**

During practice, participants were seated in front of the computer monitor with their testing forearm along the arm of the lever and their dominant hand grasping the lever handle. The task of moving the lever to replicate the goal movement pattern displayed on the monitor was explained to the participant. The experimenter and the participants reviewed templates of a sample target trajectory and superimposed feedback trajectory to ensure that the participants understood how to interpret the computer-displayed feedback. The participants were instructed to practice the goal movement and use the feedback to make their movements as accurate as possible (i.e., lower RMSE and replicate the target trajectory). Care was taken to ensure that the children understood how to interpret the augmented feedback. When the researcher determined the participants were adequately oriented to the task and the augmented feedback, the acquisition phase was begun. Participants practiced the arm movement for four 50-trial sessions. One day later, the participants returned for the retention and reacquisition phases.

**Data Analysis**
Performance accuracy was assessed separately for the acquisition, retention, and reacquisition phases. The dependent measure for accuracy was the RMSE, which is the average difference between the goal movement trajectory and the participant’s response, calculated over the participant’s total movement time (Schmidt & Lee, 2011). The RMSE was calculated for each trial and averaged into 10 trial blocks for analysis.

Separate t tests were conducted to assess group differences for age, MVPT-3 scores, Box and Block Test, and VMI scores. Repeated measures analysis of variance (ANOVA) were used to assess the effects of group, feedback and trial block. Group comparisons between the typically developing children and children with SHCP were made. For task acquisition, a 2 group (typically developing children/children with SHCP) X feedback (100% vs. 62% faded) X 20 block ANOVA with repeated measures on the last factor was used. For the retention test, a 2X2X2 (group X feedback X block) ANOVA with repeated measures on the last factor was used. Post hoc analyses were conducted to determine the locus of interactions.

Effect size was calculated as a measure of power and to determine the magnitude of between-group differences. Previous work comparing adults and adults with unilateral brain damage observed a large effect size of 1.3 (Winstein et al., 1999). In accordance with this parameter, a sample size calculation yields an expected N/group of 15 subjects for a power of 70% and 20 subjects for a power of 80%. For all statistical tests, the significance level was set at \( p < .05 \). We used SPSS, version 18.0, statistical software for all statistical analyses.
Chapter 3
Results

Demographic Information

Group mean comparisons for age, MVPT-3 scores, and Box and Block Test scores, are summarized in Table 2.

Participants in both groups demonstrated similar gross motor dexterity, as measured by the number of blocks transferred in 1 minute during the Box and Block Test (TDC: mean number of blocks = 60, SD = 7; children with SHCP: mean number of blocks = 49, SD = 9). Group means for performance on the MVPT-3 suggest both groups had normal, age-appropriate visual perception. Within each group of children, there were no significant differences between the feedback groups for age, MVPT-3 scores, or Box and Block Test scores (p > .05).

Manual Ability Classification System (MACS) levels for children with SHCP were reported by parents. For children in the 100% FB group, eight were at level II and one child was at level I. Among the children in the 62% FB group, six were at level II, three at level I, and one at level III. Although the children in the two groups varied with respect to perceived ability for bimanual tasks, no significant difference was found for the manual dexterity task (Box and Block test) completion using the dominant hand (p = .12).
Table 2

**Group Means (Standard Deviation) for Age, Visual Perception, and Manual Dexterity by Feedback (FB) Group**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Typically Developing Children</th>
<th>Children with SHCP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100% FB (n = 10)</td>
<td>62% FB (n = 10)</td>
</tr>
<tr>
<td>Age, y</td>
<td>10.4 (1.7)</td>
<td>11.2 (2.0)</td>
</tr>
<tr>
<td>Motor-Free Visual Perception Test-3</td>
<td>93.8 (5.0)</td>
<td>88.7 (8.9)</td>
</tr>
<tr>
<td>Box and Block Test&lt;sup&gt;b&lt;/sup&gt;</td>
<td>58 (6)</td>
<td>62 (7)</td>
</tr>
</tbody>
</table>

*Note. SHCP = Spastic Hemiplegic Cerebral Palsy, FB = Feedback condition.*

<sup>a</sup>Separate t tests: p<sup>1</sup>=p value for typically developing children within-group difference (100% FB and 62% FB), p<sup>2</sup>=p value for children with SHCP within-group difference (100% FB and 62% FB), p<sup>3</sup>=p value for between-group difference (typically developing children and children with SHCP).

<sup>b</sup>no. of blocks transferred per minute.

**Clinical Measures**

Data for all clinical measures completed with children with SHCP is summarized in Table 3.

*Motor-Free Visual Perception Test 3<sup>rd</sup> Ed (MVPT-3).* Seven children in the 100% FB group and seven children in the 62% FB group received a standard score between 85 and 115 on the MVPT-3, indicating that the majority of participants with SHCP had visual perceptual skills as expected for their age.

One child in each group scored slightly below age expectations, one child in the 100% FB group and two in the 62% FB group scored slightly above age expectations (Colarusso & Hammill, 2003).

*Box and Block Test of Manual Dexterity.* All participants completed the Box and Block test using both their preferred hand and their non-preferred (hemiplegic) hand. All children with SHCP performed significantly below age level.
expectations (>2 SD below the mean) with their hemiplegic hand. Five participants in the 100% FB group and eight participants in the 62% FB group also performed significantly below age level expectations while completing the task with their dominant or preferred hand. As it is commonly recognized that children with SHCP often have some degree of motor difficulty evident even on their ‘non-hemiplegic’ side, these results are not surprising (Mathiowetz et al., 1985).

Grip Strength. Sixteen of the 19 children with SHCP performed the grip task with strength significantly below age level expectations (>2 SD below the mean) with their hemiplegic hand. One participant in each FB group also performed significantly below age level expectations with their dominant or preferred hand (Mathiowetz et al., 1986).

Pinch Strength. Seventeen out of 19 children with SHCP performed the key pinch strength task significantly below age level expectations (>2 SD below the mean) with their hemiplegic hand. Six participants in the 100% FB group also performed significantly below age level expectations with their dominant or preferred hand, while no children did so in the 62% FB group (Mathiowetz et al., 1985).

Developmental Test of Visual-Motor Integration (VMI) 5th Ed. Five children in the 100% FB group and four children in the 62% FB group received a standard score between 85 and 115 on the VMI, indicating visual perception and motor skills as expected for their age. Four children in the 100% FB group and six children in the 62% FB group scored below (>1 SD below the mean) or
significantly below (>2 SD below the mean) age level expectations. Markedly lower participant scores on the VMI were not unexpected as this task requires a more complex integration of visual perceptual skills and motor performance not measured by the MVPT-3. No significant difference between FB groups was found (Beery et al., 2006).

Additional Measures completed with 11 children with SHCP.

*Two-Point Discrimination Test (2PD).* Participants were tested for tactile discrimination on both the dominant and hemiplegic hand. Discrimination ability was rated as capable (10 points), modest ability (3-9 points), or incapable (0-2 points). For the 11 children assessed, all but one participant demonstrated capable tactile sensibility for their preferred hand as measured by the 2PD test. One participant had a modest ability (Krumlinde-Sundholm & Eliasson, 2002).

*Pick-Up Test.* Participants were tested for functional sensibility using both their dominant and hemiplegic hand. Sensibility was rated according to the ratio of time needed to complete the task with and without visual feedback. The ratings are similar to those used for the 2PD test: capable (took less than 2.5 times as long as when looking), modest ability (took more than 2.5 times as long as when looking), or incapable (could not complete without looking). For the 11 children assessed, all participants demonstrated capable functional sensibility for their preferred hand (Krumlinde-Sundholm & Eliasson, 2002).
Table 3

Clinical Measures Results for Children with SHCP by Group

<table>
<thead>
<tr>
<th>Participant</th>
<th>Box and Block&lt;sup&gt;a&lt;/sup&gt;</th>
<th>MVPT-3&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Grip Strength&lt;sup&gt;c&lt;/sup&gt;</th>
<th>Pinch Strength&lt;sup&gt;d&lt;/sup&gt;</th>
<th>VMI&lt;sup&gt;e&lt;/sup&gt;</th>
<th>2PD&lt;sup&gt;f&lt;/sup&gt;</th>
<th>Pick Up&lt;sup&gt;g&lt;/sup&gt;</th>
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<td>P</td>
<td>H</td>
<td>P</td>
<td>H</td>
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<td>39*</td>
<td>87</td>
<td>16*</td>
<td>46</td>
<td>10*</td>
<td>14</td>
</tr>
</tbody>
</table>

Note. SHCP = Spastic Hemiplegic Cerebral Palsy; H = hemiplegic hand; P = preferred hand; FB = feedback; * = performance significantly below age expectations (>2 SD); - = measure not completed with participant.

<sup>a</sup>no. of blocks transferred per minute.  <sup>b</sup>MVPT-3 = Motor Free Visual Perception Test (3<sup>rd</sup> Ed).  <sup>c</sup>-<sup>d</sup>pounds.  <sup>e</sup>VMI = Beery Developmental Test of Visual Motor Integration.  <sup>f</sup>2PD = Two Point Discrimination test; C=capable; M=modest ability; I=incapable.  <sup>g</sup>standard scores with mean of 100, SD of 15.  <sup>h</sup>Pick up test; C=capable; M=modest ability; I=incapable.
Overall Results

Both groups of children used visual feedback to improve motor performance during skill practice. Children receiving 62% feedback performed with significantly greater error than children receiving 100% feedback during acquisition ($p = .012$), retention ($p = .017$), and reacquisition tests ($p = .042$). Children with SHCP performed with significantly greater error than TDC during the acquisition phase ($p < .001$), retention ($p = .031$), and the reacquisition test ($p = .001$). See Figure 6 for performance accuracy across all groupings. Performance error means (RMSE) for each acquisition session, retention, and reacquisition according to feedback level and group can be found in Table 4.
Figure 6. Performance accuracy across all groupings. Block means (± SE bars) for root mean square error (RMSE) during acquisition, retention (no feedback [FB]) and reacquisition (with FB) phases for typically developing children (TDC) and children with spastic hemiplegic cerebral palsy (CP).
### Table 4

**Performance Error (Root Mean Square Error [RMSE]) Block Means (SD) for Acquisition (Day 1) and Retention (Day 2) by Feedback (FB) Group**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Typically Developing Children</th>
<th>Children with SHCP</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n = 20)</td>
<td>(n = 19)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100% FB (n = 10)</td>
<td>62% FB (n = 10)</td>
<td>p^1</td>
</tr>
<tr>
<td>RMSE</td>
<td>15.55 (2.8)</td>
<td>18.33 (5.6)</td>
<td>.04*</td>
</tr>
<tr>
<td>Acquisition</td>
<td>20.03 (6.0)</td>
<td>25.03 (9.2)</td>
<td>.092</td>
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<tr>
<td>Session 1</td>
<td>24.76 (8.1)</td>
<td>26.75 (8)</td>
<td>.39</td>
</tr>
<tr>
<td>Session 2</td>
<td>14.58 (5)</td>
<td>15.68 (4.5)</td>
<td>.52</td>
</tr>
<tr>
<td>Session 3</td>
<td>11.48 (2.7)</td>
<td>16.28 (5.3)</td>
<td>.006**</td>
</tr>
<tr>
<td>Session 4</td>
<td>11.39 (2.3)</td>
<td>14.62 (4.2)</td>
<td>.015*</td>
</tr>
<tr>
<td>Retention (no-FB)</td>
<td>13.23 (3.8)</td>
<td>19.48 (6.4)</td>
<td>.017*</td>
</tr>
<tr>
<td>Reacquisition</td>
<td>15.28 (3.4)</td>
<td>12.04 (3.6)</td>
<td>.32</td>
</tr>
<tr>
<td>Block 1</td>
<td>15.20 (9.2)</td>
<td>15.28 (3.4)</td>
<td>.092</td>
</tr>
<tr>
<td>Block 2</td>
<td>11.26 (2)</td>
<td>12.04 (3.6)</td>
<td>.013**</td>
</tr>
</tbody>
</table>

Note. FB = Feedback condition; TDC = Typically Developing Children; SHCP = Spastic Hemiplegic Cerebral Palsy.

aGroup (TDC, children with SHCP) x FB (100%, 62%) x block repeated-measures analysis of variance results: p^1=p value for TDC within-group difference (100% FB and 62% FB), p^2=p value for children with SHCP within-group difference (100% FB and 62% FB), p^3=p value for between-group difference (TDC and children with SHCP).

*p < .05. **p < .01. ***p < .001.
Acquisition phase.

Overall results. During the acquisition phase participants practiced the motor task for 200 trials (four 50-trial sessions). All children benefitted from practice and performed the movement with increased accuracy over the course of trials. Figure 7 provides a typical example of the change in improvement accuracy from early to late practice.

![Figure 7](image)

Figure 7. Performance of a typically developing child in early and late practice (day 1). The blue line represents the target, and the dashed line represents the child's movement trajectory (Sullivan et al., 2008).

Subgroup results. Across the entire acquisition phase, children with SHCP performed with significantly greater error than TDC ($p < .001$; group main effect). Performance accuracy throughout acquisition trials was similar for children with SHCP, regardless of FB condition ($p = .092$). See Figure 9 for individual session details. For TDC, performance was similar during sessions 1 and 2, but as FB decreased for those in the faded FB group, differences became evident. During sessions 3 and 4, when FB was presented for 50% or 25% of trials, TDC children
performed the movement with significantly more error than TDC receiving frequent (100%) FB ($p = .006, p = .015$, respectively). See Figure 8 for details.

No group x FB condition interaction existed during the acquisition phase ($p = .476$). 

*Post hoc* analysis, a two group comparison by FB condition, revealed additional findings of interest: TDC were significantly more accurate across the entire acquisition phase than children with SHCP practicing with the same feedback frequency (100% FB group, $p = .024$; 62% FB group, $p = .006$). See Figures 10 and 11 for details.
Figure 8. Performance accuracy of TDC by FB condition. Block means (± SE bars) for root mean square error (RMSE) during acquisition, retention (no feedback [FB]) and reacquisition (with FB) phases for typically developing children (TDC). Significant differences in performance were evident between the groups of TDC in different FB conditions during acquisition session 3 ($p = .006$), session 4 ($p = .015$), and retention ($p = .017$). When FB was reintroduced during reacquisition, performance accuracy was similar between the FB conditions ($p = .32$).
Figure 9. Performance accuracy of children with SHCP by FB condition. Block means (± SE bars) for root mean square error (RMSE) during acquisition, retention (no feedback [FB]) and reacquisition (with FB) phases for children with spastic hemiplegic cerebral palsy (SHCP).
Figure 10. Performance accuracy of children in 100% FB condition. Block means (± SE bars) for root mean square error (RMSE) during acquisition, retention (no feedback [FB]) and reacquisition (with FB) phases for typically developing children (TDC) and children with spastic hemiplegic cerebral palsy (CP). Significant differences between groups of children were evident during acquisition sessions 3 (p = .014) and 4 (p = .004), retention (p = .048), and reacquisition (p = .016).
Figure 11. Performance accuracy of children in 62% FB condition. Block means (± SE bars) for root mean square error (RMSE) during acquisition, retention (no feedback [FB]) and reacquisition (with FB) phases for typically developing children (TDC) and children with spastic hemiplegic cerebral palsy (CP). Significant differences between groups of children were evident during acquisition session 2 ($p = .006$), session 3 ($p = .045$), and session 4 ($p = .014$) and during reacquisition ($p = .011$).
Retention phase: No feedback retention test.

*Overall results.* The no-feedback retention test provided a measurement of learning subsequent to the previous days’ practice. There was a significant main group effect for children with SHCP who performed poorly compared to TDC ($p = .031$). Practice in a reduced frequency (62%) FB condition led to significantly less accurate performance during retention compared to practice with frequent (100%) FB ($p = .017$).

*Subgroup results.* There was a significant FB effect for children in the frequent FB (100%) condition; children with SHCP who practiced with 100% FB had less accurate movement patterns than TDC ($p = .048$). That is, they had more error during retention in comparison to their practice performance. The groups of children that practiced the task in the faded frequency FB condition (62%) performed similarly to each other ($p = .20$) in the no feedback retention test.

When TDC practiced under reduced FB (62%) conditions, their performance during retention was significantly less accurate than TDC who practiced with frequent FB ($p = .017$). Children with SHCP performed similarly during retention regardless of FB conditions during practice ($p = .186$).

Reacquisition phase: With feedback retention test.

*Overall results.* All children demonstrated improvement in performance accuracy during the reacquisition phase. Group means indicate that, when feedback was reintroduced, children were able to match their best performance from the acquisition practice phase (see Table 4).
*Subgroup results.* Even so, across the 2 trial blocks, children with SHCP performed with significantly more error than TDC ($p = .001$). There was a significant FB effect with all children receiving 100% FB performing more accurately than children receiving 62% FB ($p = .042$).

Within group data demonstrates children with SHCP in both FB conditions were able to benefit from the reintroduction of FB, with a trend toward performance with less error (greater accuracy) for the 100% FB group ($p = .092$). *Post hoc* analysis showed a significant within FB group effect. During the reacquisition phase, children with SHCP had more error than TDC who practiced in the same feedback condition (100% FB, $p = .016$; 62% FB, $p = .011$).
Chapter 4
Discussion

It is unclear how motor and central nervous system differences in children with cerebral palsy impact their use of feedback in motor skill acquisition. The intent of this study was to determine if children with spastic hemiplegic cerebral palsy (SHCP) were able to use augmented feedback in a manner similar to typically developing children (TDC). Specifically, we investigated the effect of visual feedback on the performance and learning of an upper extremity motor skill in children with SHCP as they practiced a discrete movement with their less affected arm.

Overall, results indicate that typically developing children and children with SHCP were able to use augmented visual feedback to improve motor performance during practice of an upper extremity motor skill. Both groups of children demonstrated significant improvements in performance accuracy over the duration of the acquisition phase. Although performance decreased with the removal of feedback during retention, learning was evidenced by a return to end of practice level performance when visual augmented FB was reintroduced during the reacquisition phase.

The findings support the first hypothesis that, during acquisition and retention phases, children with SHCP will have more error than a control group of typically developing children. When children with SHCP were provided with the same amount of practice trials and augmented visual FB as a group of TDC, they performed with more error (i.e., less accuracy) during the acquisition phase and
retention test. There was no group x FB condition interaction, but children with SHCP were significantly less accurate in comparison to TDC in the same FB condition.

It is possible that the error discrepancy stems from learning, sensory processing, or proprioceptive differences within the CP population. Impairments related to attention and executive function (Bottcher, Flachs, & Uldall, 2010), deficits in joint position sense and kinesthesia (Wingert, Burton, Sinclair, Brunstrom, & Damiano, 2009), visual perceptual skills (Burtner et al., 2006), as well as decreased speed and dexterity during handwriting (Bumin & Kavak, 2010) have been well documented. With respect to children with SHCP, it would seem that differences in interpretation of proprioceptive and visual input add an additional challenge to the cognitive demand required during motor skill acquisition.

The results are consistent with previous literature detailing motor learning differences after unilateral brain damage from stroke (Winstein et al., 1999). Participants completed an experimental protocol closely matching that of the current study: learning a discrete upper extremity movement including acquisition, retention, and reacquisition trials in either a 100% or faded (67%) FB condition. Adults with unilateral stroke-related brain damage had more error during all phases in comparison to a control group of adults without neurological deficits. The authors suggest that stroke related damage in the sensorimotor area impacts motor skill control and execution, but not the learning of the skill.
itself. Present data similarly suggests the use of FB for motor skill learning might be impacted by brain damage in the sensorimotor areas.

Examination of group means of children with SHCP across acquisition sessions, it is clear that accuracy increases and variability (SD) consistently decreases with practice for both FB groups. It is possible that additional practice sessions completed either on the same, or subsequent day, are necessary for children with SHCP to maximize learning and demonstrate best performance.

Practice specificity is especially critical with respect to available visual FB (Gordon & Magill, 2011). In general, if visual FB is provided during practice, performance during retention and transfer tests will be best with the same visual FB available. Research suggests performance and learning are dependent on the creation of a specific sensorimotor representation integrated with motor movements (Wierinck, Puttemans, Swinnen, & van Steenberghe, 2005).

Evidence of neural activity and reliance upon visual FB beyond the duration of practice sessions has recently been validated through fMRI imaging (Ronsse et al., 2011). In this study, participants practiced a novel, bimanual motor task with augmented FB of either visual input or auditory pacing. The group with visual support had increased brain activity in sensory specific areas during practice, as well as after the augmented FB was no longer available. Individuals provided with auditory augmented FB had less neural activity, particularly in areas related to cognitive and sensory aspects of motor learning. Further evidence suggests that if augmented visual FB (i.e., real time movement trajectories) is added during retention and transfer tests, it interferes with the use of cognitive,
propriocceptive information relied upon during practice, and performance accuracy decreases (Puttemans, Vangheluwe, Wenderoth, & Swinnen, 2004). It seems that certain strategies are stored internally as a visual representation that does not prove useful if the original source of feedback is not available during retention or transfer tests, thereby degrading performance (Schmidt & Lee, 2011).

Hemayattalab and Rostami (2010) completed a study investigating the impact of visual FB presented at different frequencies (0%, 50%, 100% KR) on the ability of children with SHCP to learn a dart throwing skill. Visual FB (re: target accuracy) was provided to children on the dart screen. Children in the 100% FB group had the best performance during acquisition. Conversely, during retention tests conducted three days later, the 100% FB group had the weakest (least accurate) performance, and those in the 50% FB group performed the strongest, indicating the ‘most’ learning had occurred. The authors concluded that too much FB is detrimental to learning for children with SHCP.

Current findings conflict with those presented by Hemayattalab and Rostami (2010). In our study, all children with SHCP acquired a novel motor skill with similar performance accuracy, even when different FB conditions were provided during practice. Group mean error values (RMSE) during acquisition, retention, and reacquisition phases did not show a statistically significant difference, providing confirmation for this conclusion. This contradicts the second hypothesis that, during both acquisition and retention phases, children with SHCP who receive feedback after every practice trial (100%) will have less
movement error than those who receive reduced feedback frequency (62%) during practice.

A trend for decreased accuracy among children with SHCP in the reduced frequency FB condition is apparent for the acquisition phase. The trend re-emerges during the two, 10-trial delayed retention with FB blocks (reacquisition). During reacquisition, children with SHCP who practiced with 100% FB were able to match their best performance during practice with decreased variability across the entire session (as indicated by block mean SD ± 3.4, 4.1, respectively). The children with SHCP who practiced with reduced FB had more error and variability for the initial block, but were able to increase their accuracy with continued trials during the second reacquisition block (as indicated by block mean SD ± 9.2, 7.4, respectively). It is clear that 100% FB was beneficial for children with SHCP who practiced with both FB levels.

The findings in the current study are consistent with those presented in a 2008 study (Sullivan et al., 2008) confirming that, when practice and feedback conditions provide an optimal challenge, learning is fostered. If the cognitive/information processing requirements of the task are too high, learning is not as expedient. Regarding within group performance differences due to FB condition, neither typically developing children, nor children with SHCP, performed statistically different from each other during reacquisition. However, children with SHCP approached significance, and this finding supports the conclusion that 100% FB benefits learning and performance accuracy for children with SHCP.
Current study results align with previous research conclusions that visual FB supports improved motor skill acquisition. Several recent studies, specific to children with SHCP, detail the benefits of augmented visual FB for motor skill acquisition. Findings conclude visual information supports action planning of movements (Crajé, Aarts, Sanden, & Steenbergen, 2010), mirror FB (of the less impaired arm) improves motor control (Feltham, Ledebt, Deconinck, & Savelsbergh, 2010), and static visual FB supports limb matching accuracy and joint-position sense (Smorenburg, Ledebt, Feltham, Deconinck, & Savelsbergh, 2011). Further confirmation comes from Wingert, Burton, Sinclair, Brunstrom, and Damiano (2009) who found bilateral proprioceptive deficits in participants with SHCP and an indication that visual FB benefits motor skill practice and learning on the preferred side as well as on the more affected side.

**Study Limitations**

The sample size for this study was small for several reasons. This work was an extension of previous research from Sullivan, Kantak and Burtner (2008) who were able to demonstrate robust findings of differences between young adults and children in the effects of visual FB on motor learning. This was accomplished with a sample size similar to the current study. Additionally, to accurately measure motor skill acquisition for children with SHCP with the experimental protocol utilized, it was thought important to adhere to inclusion criteria guidelines for academic performance and attention capabilities. This proved to be more of a challenge than anticipated and took a considerable length of time and coordination to accomplish. Participants were grouped by
convenience. A larger sample would be needed to get a true picture of differences in performance according to gender, age, CP diagnosis, or severity of impairments.

The feasibility of conducting a similar experimental study of motor skill acquisition with children has been demonstrated (Sullivan et al., 2008). Even so, we recognize that testing and experimental research with children is more complex. This might be especially true for children with SHCP and their families. The mobile equipment set up was developed with this in mind. Fourteen of the 19 children with SHCP in the study completed data collection in private or community settings. It is possible that this variation of location might have impacted their performance. Familiar surroundings or the presence of family members, for example, could have unintentionally provided encouragement not experienced by participants completing the task in a lab setting.

Conclusions and Future Direction of Research

Interpretation of study results is in agreement with several recommendations from Wingert et al. (2009): 1) vision should be engaged during the learning and practice of movements, 2) reliance on visual FB is expected and likely beneficial early in the rehabilitation process, and 3) additional benefits might result from practicing motor tasks with gradually decreasing visual input. This implies that therapists should be thinking about the amount of practice and frequency of FB provided during intervention. We can conclusively say children with SHCP need more practice with visual FB than TDC. At this point, it is unclear if that additional practice will be most effective with 100% or 62% FB.
Conclusions reached by the current study provide pertinent information for clinicians and researchers. Additional studies with a larger sample size will support generalization of findings across the CP population. Research including participants with a more extensive range of severity and/or impairments will potentially provide further insights. Research detailing differing responses to FB by children with left vs. right hemiplegia offers exciting possibilities. A larger sample size will also be informative in this area. It is anticipated that a combination of these understandings and current study results will be crucial in the development of specific clinical applications.
Cerebral palsy (CP) is a common childhood disorder beginning early in life and impacting multiple areas of development. Most notable are motor deficits that interfere with functional tasks and mobility, although various cognitive and sensory deficits are frequently associated (Batshaw et al., 2007; Rosenbaum et al., 2007). CP is one of the most common causes of physical disability in early childhood (Krageloh-Mann & Cans, 2009) and children with CP constitute the largest clinical group seen in pediatric occupational therapy (Novak et al., 2009). Rehabilitation efforts most often address the impact of impairments on daily activity. Current research focuses on furthering our understanding of the condition and application to support effective treatment methodologies. To maximize our role as therapists, it is crucial to have a broad understanding and background of the condition.

Current thinking clarifies CP as a descriptor, or “umbrella term”, encompassing a heterogeneous group rather than a specific diagnosis. CP references a clinical condition, which may or may not be mutually exclusive from the cause of the condition (Blair, 2010). The most recent definition from the International Workshop on Definition and Classification of Cerebral Palsy states: Cerebral Palsy describes a group of permanent disorders of the development of movement and posture, causing activity limitation, that are attributed to non-progressive disturbances that occurred in the developing
fetal or infant brain. The motor disorders of cerebral palsy are often accompanied by disturbances of sensation, cognition, communication and behavior, by epilepsy, and by secondary musculoskeletal problems. (Rosenbaum et al., 2007, p. 9)

Word choice in the definition highlights that the condition results from an insult occurring early in development, generally within the first few years of life, before key functional motor milestones have been achieved (Rosenbaum et al., 2007). A definitive diagnosis of CP is often not made until after the age of 3 (Krageloh-Mann & Cans, 2009). CP can be directly attributed to an insult to the brain that does not change over time. The impairments, activity limitations, and accompanying disturbances may be directly related or secondary to functional changes over time (Rosenbaum et al., 2007).

Most studies indicate CP occurs in approximately 2.0-2.5:1000 live births within the general population (Batshaw et al., 2007). This rate has remained fairly consistent over the past 50 years, although recent publications show higher rates within the United States. An analysis of National Health Interview Surveys data for the years 1997-2008 indicates .39 - .43% of children 3-17 years old in the US are diagnosed with CP. Also of interest is the difference between prevalence among children living < 200% poverty level (.41%) and those living >= 200% poverty level (.34%) (Boyle et al., 2011). Data from the Autism and Developmental Disabilities Monitoring Network reports the overall prevalence among 8-year-olds in four areas of the United States to be .33% in 2006. Prevalence was noted to be markedly lower for Hispanic children (.22%) (Kirby et
al., 2011). It is generally understood that the incidence of CP increases as birth weight and gestational age decrease (Cans et al., 2008; Krageloh-Mann & Cans, 2009).

Classification of children with CP can be specified according to area of their brain lesion (limb distribution), type of motor impairment, or their functional level (Cans et al., 2008; Gorter et al., 2004; Morris, 2007). Classification by type of motor impairment is most common and encompasses spastic, dyskinetic, and ataxic forms of CP.

Spastic CP, the most common type, represents approximately 85% of cases and involves injury to the cortex and pyramidal tracts resulting in excess muscle tone or spasticity (Batshaw et al., 2007; Kirby et al., 2011; Krageloh-Mann & Cans, 2009; Reid et al., 2011; Towsley et al., 2011). Individual manifestations are further characterized by body/limb distribution with hemiplegia indicating children with impairment predominantly on one side of the body, diplegia indicating impairment in all 4 limbs with predominantly LE involvement, and quadriplegia indicating involvement of all 4 limbs and possibly head and trunk movements. Classifying in this manner is common, but has become increasingly controversial due to discrepancies between the distinctions and inconsistencies with usage (Cans et al., 2008). The Surveillance of Cerebral Palsy in Europe (SCPE) working group, comprised of numerous researchers and professionals familiar with CP, published a report recommending the terms Bilateral Spastic (BS-CP) and Unilateral Spastic (US-CP) (Krageloh-Mann &
Cans, 2009; Rethlefsen et al., 2010). Use of this terminology requires recognition that ‘bilateral spastic CP’ is inclusive of diplegia and quadriplegia cases.

Dyskinetic CP and ataxic CP represent approximately 10% and 5% of cases, respectively (Blair, 2010; Krageloh-Mann & Cans, 2009; Reid et al., 2011; Towsley et al., 2011), and relate to injury in the extrapyramidal tract regions resulting in varying tone and, typically, whole body involvement. The dyskinetic subtype is most often related to damage in the basal ganglia or thalamus regions, while ataxia results from injury in the cerebellar area (Blair, 2010).

Historically, the majority of CP cases have been thought to result from “birth asphyxia”, or injury due to an interruption of either the blood or oxygen supply during the birth process. Research has clarified that this is only the cause in a minority of situations (Batshaw et al., 2007; Lundy-Ekman, 2007). Rather, in at least 80% of cases, CP is the result of brain lesions or maldevelopments (Krageloh-Mann & Cans, 2009) specific to the cerebrum, cerebellum, and brain stem areas that impact the CNS. The remaining 10-20% of cases are due to abnormal brain development related to genetic or unknown reasons (Batshaw et al., 2007; Blair, 2010).

Spastic hemiplegic CP (SHCP) is the result of white matter damage impacting motor tracts. In congenital SHCP, injury to the child’s brain occurs during prenatal development. Prenatal brain development is time period specific and patterns of manifestation have been shown to correlate with both lesion location and timing of the insult (Blair, 2010; Towsley et al., 2011). Abnormal brain development or malformations of the CNS typically occur during the first or
second trimester. Periventricular white matter (PVWM) injuries primarily occur early during the third trimester when tissues near the lateral ventricles are particularly vulnerable (Krageloh-Mann & Cans, 2009). Fluctuations in cerebral blood pressure, intraventricular hemorrhage (IVH), or infarctions can interrupt development of motor tracts in this area. The PVWM area is where fibers for motor and muscle control of the legs develop, and the severity of the event is positively correlated with amount of white matter damage (and accordingly, the type CP, and level of resulting involvement). Periventricular leukomalacia (PVL), a pattern of white matter lesions or cysts, can occur when the PVWM area is subjected to low oxygenation or low blood flow. PVL can follow an IVH incident or occur independently (Batshaw et al., 2007).

Advances in technology and brain imaging research provide insight not previously available. In a study presenting analysis of MRI images in the CP population of children from the SCPE database, abnormal findings were most common among the spastic subtypes, noted in approximately 90% of cases (Krageloh-Mann & Cans, 2009). Imaging studies have corroborated previous understandings that children with unilateral spastic CP were reported significantly more among term births (37%) compared to preterm births (22%) (Himpens et al., 2008). The literature presents conflicting information regarding the specific mechanism of injury in relation to the infant’s gestational age. One study states that in preterm births, focal or post hemorrhagic periventricular lesions occurred significantly more, while cortical/deep grey matter lesions (due primarily to MCA infarcts) were found to occur significantly less often (Krageloh-Mann & Cans,
A 2004 study (Kulak & Sobaniec, 2004) found PVL patterns in 49% of children with SHCP, and 82.7% of those were term births. The use of MRI studies will continue to support understandings in this area.

Increased incidence of CP is noted with male births and multiple births in comparison to female or singleton births (Blair, 2010). Although not as thoroughly documented, other potential risk factors include social disadvantage, maternal medical condition, pregnancy related conditions, and certain infections. A recent article in the *Journal of the American Medical Association* found a correlation between post term birth (at 42 weeks or later) and an increased risk of CP, although further research related to the risks for specific subtypes and clinical implications is recommended (Moster, Wilcox, Vollset, Markestad, & Lie, 2010).

In her discussion of epidemiology, Blair (2010) asserts that any factor related to a (very) preterm birth can precede a potential pathway for CP.

While technology and research innovations continually provide new information as to what occurred structurally or otherwise during brain development, it is not currently possible to definitively delineate causal factors in every situation (Rosenbaum et al., 2007). In many cases, the child with CP may be the result of multiple risk factors.

**Impact of CP on Function**

In observing children with CP, the diversity that exists across individuals must be recognized. Varying combinations of pyramidal and extrapyramidal signs are often demonstrated. Specific subtypes result from lesion location, the amount of damage, and stage of brain development at the time of injury.
It is commonly understood that all individuals with CP have problems with movement and posture (Batshaw et al., 2007). Spastic hemiplegia impacts one side of the child’s body more than the other, with the arm typically more involved than the leg. The involved side is contralateral to the area of brain affected (Batshaw et al., 2007).

Hemiplegia is often accompanied by a certain level of involvement on the less affected side impacting both motor execution and motor planning abilities of the child (Janssen & Steenbergen, 2011; Steenbergen, 2006). Findings of decreased hand skill performance and speed (Dellatolas et al., 2005), motor planning deficits specific to object manipulation (Steenbergen et al., 2007), and delayed development of motor planning (Janssen & Steenbergen, 2011) have been reported in these children. Involvement on the less affected side often complicates accurate classification (Blair, 2010; Rethlefsen et al., 2010; Rosenbaum et al., 2007).

The presence, or absence, of impairment, along with degree of severity contributes to an individual’s classification and diagnosis. Historically, classification was more subjective with severity commonly described by the child’s walking ability. Variability existed among professionals due to inconsistent use of terminology and descriptions (Cans et al., 2008; Morris, 2007). As the aim of research is to both understand and develop treatments for a particular disorder, clear, consistent use of language and descriptions among professionals and providers is needed. Current trends seem to favor classification according to
the individual’s function and less reliance on describing underlying impairments (Blair, 2010; Rosenbaum et al., 2007).

Recently, standardized measures have been developed that foster such classification of children by function along with motor severity (Cans et al., 2008). The most widely recognized, used, and accepted of these measures are the Gross Motor Function Classification Scale (GMFCS; (Palisano et al., 1997) and the Manual Ability Classification Scale (MACS; (Eliasson et al., 2006). Both scales have been shown reliable and valid and are accessible online.

The GMFCS provides a description of age-specific abilities and gross motor function across five levels (Palisano et al., 1997). Classification is determined by observation of self-initiated movement, with a focus on sitting and walking. Level I classification indicates children who have the most independence; children with motor function at a level V classification have the least functional independence. Distinctions between levels are based on each child’s usual functional performance and their need for assistive technology (“CanChild Centre for Childhood Disability Research,” n.d.; Gunel, Mutlu, Tarsuslu, & Livanelioglu, 2009). Parental and clinician ratings have shown strong agreement indicating the tool can support effective communication about a child’s gross motor function (Mutlu, Kara, Gunel, Karahan, & Livanelioglu, 2011).

The MACS was developed to provide a system for classifying bimanual hand use in children with CP (Eliasson et al., 2006). It is based on self-initiated handling of objects (with one or two hands) during daily activities in home, school & community settings, as well as the level of assistance needed. The MACS form
describes five levels and provides distinctions between the levels to facilitate accuracy among users. Level I relates to children with minimal limitations impacting performance of daily living skills. Children classified at level V have severely limited object handling abilities (Gunel et al., 2009).

A high correlation exists between clinical subtype and functional levels as measured by the GMFCS and MACS (Gorter et al., 2004; Gunel et al., 2009). Most children with spastic hemiplegia function at GMFCS level I - III, with the vast majority at level I (Gorter et al., 2004; Kirby et al., 2011). Independent mobility, perceived as a major indicator of participation level and quality of life, is usually achieved by children classified at GMFCS levels I and II (Kirby et al., 2011). Regarding hand use during daily activities, a study including 60 participants (aged 4–15) with spastic hemiplegia, found 43% were rated at MACS level I, 45% at MACS level II, and 12% at level III. No significant differences were noted between younger and older children across MACS levels (Gunel et al., 2009). Beyond the scope of classification for research purposes, the goal of accurate assessment of children with CP is to systematically note progress over time, support cross discipline clinician communication, and foster implementation of effective therapeutic interventions (Gunel et al., 2009).

In addition to movement and motor control difficulties, CNS damage in children with spastic hemiplegia may result in a variety of associated impairments (Batshaw et al., 2007). The most common of these are difficulties connected to cognition, learning, and sensation (Batshaw et al., 2007). Overall, findings present consistent positive correlations between the number and degree of
associated impairments and severity of motor difficulties a child experiences (Batshaw et al., 2007; Himpens et al., 2008; da Costa et al., 2004). Much research has been conducted with the aim of clarifying the impact of these associated impairments, particularly with regard to a child's function. The most pertinent findings related to all children with CP are:

- Epilepsy occurs in 26–46% of those with the spastic hemiplegia subtype (Himmelmann & Uvebrant, 2011; Kirby et al., 2011; Kulak & Sobaniec, 2004), with this group exhibiting the highest incidence of seizures. One study noted an increased rate of epilepsy for children with severe hand dysfunction in comparison to those with mild or moderate hand dysfunction (Kulak & Sobaniec, 2004).

- Learning difficulties are often present even for children demonstrating average intelligence (Batshaw et al., 2007; Himmelmann & Uvebrant, 2011). Hemiplegia is often the result of an infarction of the middle cerebral artery that supplies cortical and subcortical areas likely related to focused attention and motor executive function. As a result, it is not surprising that specific findings related to impaired attention and executive function resulting in slower task performance and potentially impacting known social and learning problems have been reported in children with CP (Bottcher et al., 2010).

- Visual impairments specific to children with spastic hemiplegia include homonymous hemianopsia (loss of one part of the visual field) (Batshaw et al., 2007),
atypical gaze patterns (Steenbergen et al., 2007), and visual acuity below norms (da Costa et al., 2004).

• Deficits in joint-position sense, kinesthesia, and impaired tactile perception have been reported for the dominant side as well as significant deficits on the non-dominant side (Wingert, Burton, Sinclair, Brunstrom, & Damiano, 2008; Wingert et al., 2009).

Although Kulak (2004) reports children with left hemiplegia and right hemiplegia demonstrate comparable clinical presentations, this is primarily relative to birth related factors such as pattern of hemiparesis, arm vs. leg severity, and prenatal risk indicators. Research investigating functional and school performance presents a different view.

As part of his study on bilateral hand skills in children with hemiplegic and diplegic CP, Dellatolas (2005) related performance on neuropsychological tests, a computerized peg moving task, and daily living tasks to the children’s use of their affected and unaffected hand. The results show some differences between RHCP and LHCP groups: left hand impairment was more associated with visuospatial/counting performance; right hand impairment with phonological skill deficits. Even so, for the goal of supporting the needs of school-aged children, the researchers feel a focus on overall hand function, rather than the side of involvement, is warranted (Dellatolas et al., 2005).

In a study investigating visual perceptual skills and school function of children with SHCP in regular education settings, all participants demonstrated significantly lower scores on non-motor and visual motor measures (Burtner et
al., 2006). Subgroup analysis revealed that children with left hemiplegia (primarily right hemisphere lesions) scored significantly lower than children with right hemiplegia. Researchers suggest the visual perceptual demand of certain tasks is a contributing factor. Bumin (2010) adds further detail with regard to handwriting skill, explaining that children with right hand dominance (left hemiplegia) were significantly less competent at handwriting than their right-dominant peers without CP. The measures used in the study highlight numerous factors impacting handwriting skill: impaired proprioception of the less affected side, impaired upper extremity bilateral coordination, speed and dexterity, decreased visual and spatial perception, and deficits in visual-motor organization and tactile-sensation.

A recent study of MRI findings (Himmelmann & Uvebrant, 2011) reports relevant correlations between timing of lesions, the type and severity of motor deficits, and the incidence of associated conditions. For those with white matter lesions, the most common finding, 100% of those born at term were functioning at GMFCS levels I or II. In contrast, among those born preterm, 54% performed at GMFCS level I or II and 42% at levels IV or V. Unilateral spastic CP was most common among those with MRI’s indicating maldevelopments, white matter lesions, cortical/subcortical lesions, or ‘normal’ MRI findings. Accompanying impairments were most prevalent among participants with cortical/subcortical lesions and least prevalent among those with PVWM lesions. Children with few or no accompanying impairments were associated with PVWM lesions or normal MRI findings. Mild motor deficiency was correlated with less associated
impairments and PVWM lesions.

The combined effect of motor and associated impairments is connected to activity limitations and an increased need for health care services and intervention to support both the individual and their family (Boulet et al., 2009; Boyle et al., 2011; Cans et al., 2008; Mutlu, et al., 2010). A recent study of long-term outcomes of CP indicates the impact of impairments strongly influences an individual’s functional activity, leisure participation and quality of life far beyond the childhood years (Mesterman et al., 2010). An understanding of the needs of each child related to their clinical presentation including associated impairments therefore allows professionals to plan appropriate intervention for maximum function and participation.

**Motor Learning**

The impact of impairments is critical information for both researchers and therapists. Even so, as CP is considered to primarily influence motor control and movement, motor learning is an equally if not greater important focus of research. Motor learning research investigates the acquisition or modification of movement generated by individuals with the goal of developing skilled movements or actions (Shumway-Cook & Woollacott, 2012). Effective motor learning is thought to primarily depend upon the practice parameters and feedback conditions in place during the individual’s learning. Making meaning of adult and child motor learning research findings, in the context of therapy for children with CP, is the ultimate goal of this review.
For research purposes, a distinction must be made between learning and performance. Performance is considered a temporary change demonstrated during practice, while learning refers to a ‘relatively permanent change’ resulting from practice. Learning is most often measured or inferred from observation of behavior (Shumway-Cook & Woollacott, 2012). Motor learning (of a skill or movement) is measured by specific retention or transfer tests that provide concrete, observable data. Rehabilitation strategies that maximize learning require an understanding of the processes associated with skill acquisition and motor learning.

Early research and theories of motor learning have contributed concepts that continue to be applied and challenged. Adams’ closed loop theory states that the quality of learning is directly related to accurate movement during practice. This implies that incorrect movements during practice serve to reinforce patterns of error and should be considered harmful (Schmidt & Wrisberg, 2008). Schmidt’s schema theory challenges this idea and asserts that motor schemata are best developed through variable practice where the same task is practiced with differing duration, object weights, or goal distances. The variable practice provides optimal application of the learned skill and transfer to new or novel tasks (Schmidt & Lee, 2011; Wulf, 1991).

**Practice.** Practice is considered the most important factor impacting motor learning and skill acquisition (Shumway-Cook & Woollacott, 2012). The power law of practice, as described by Schmidt & Lee (2011), details that performance is directly related to the amount of improvement yet to achieve. The
amount of practice is critical during early periods when new tasks often improve rapidly. Later, as practice continues, performance tends to improve in slower increments (Shumway-Cook & Woollacott, 2012).

Although detailed research regarding the manipulation of practice conditions, and subsequent impact on skill acquisition is beyond the scope of this review, the contribution of practice and experience to the development of motor skills must be acknowledged. Further consideration of how contextual surroundings, practice amounts, and cognitive effort relate to the benefits of practice for adults in comparison to children will be addressed later in this review.

Feedback. In addition to practice, some form of feedback is thought necessary for learning to occur (Shumway-Cook & Woollacott, 2012). Feedback is considered any information the learner gets about how they are performing during practice. When learning motor skills, feedback is thought to both facilitate goal attainment and provide motivation for continued practice (Gordon & Magill, 2011). Inherent feedback (also referred to as intrinsic feedback) is provided by an individual’s sensory systems and includes visual, auditory, and somatosensory information stemming from movement. Inherent FB sometimes provides enough information about the result of the movement made, such as in the case of missing the trash can when throwing out an empty container. But, frequently, additional information, such as needing to start with your arm higher, is needed to achieve success (Schmidt & Lee, 2011).

Augmented feedback (FB) is any additional information the learner receives about their performance during practice. Augmented FB (also referred
to as extrinsic feedback) should be verbalizable, but may be presented in a variety of formats (verbal, visual, tactile). It becomes a reference for movement patterns and can be used along with inherent FB to facilitate learning, error recognition, and correction (Schmidt & Lee, 2011). Knowledge of results (KR) is augmented FB specific to the movement outcome in relation to the desired goal movement. Knowledge of performance (KP), is augmented FB related to the movement pattern itself. KP is more focused on the correction of improper movements and patterns than the outcome of the movement. KP often gives information about some aspect of which the person is unaware (i.e. blood pressure changes, limb positioning) (Schmidt & Lee, 2011).

**Feedback frequency.** Considerable research has been conducted on the manipulation of feedback frequency during practice sessions. Motor learning theory traditionally understood frequent KR as beneficial for learning (Wulf, Schmidt, & Deubel, 1993). This viewpoint changed when the use of retention and transfer tests as a measure of learning presented information in direct conflict (Winstein et al., 1999). A number of studies in the late 1980’s and early 1990’s contributed to this shift. A study by Winstein and Schmidt (1990) is presented as one example. Participants learned a discrete motor skill that involved moving a lever arm in the horizontal plane to match a target goal line presented on a computer screen prior to each trial. Visual feedback in the form of a line depicting the individual’s movement superimposed over the goal line was provided after movement completion. One group of adults received this feedback about performance error after every movement trial (100% frequency feedback
condition). The other group received feedback after every trial early in practice and with decreasing frequency as practice continued (50% frequency condition). Learning (motor skill memory) was determined by performance on a delayed retention test, without feedback, and a reacquisition test, with feedback re-introduced, both tested on the day following acquisition sessions. While no difference was found between the two groups for performance during acquisition sessions, results of the delayed retention tests showed participants in the 50% frequency condition performed with significantly less error. Researchers concluded that providing KR 100% of the time resulted in increased error, and was detrimental to skill acquisition.

These findings added to the growing body of knowledge suggesting instantaneous and/or frequent FB conditions interfere with the use of inherent FB and information processing functions that would otherwise be available to further learning and application to the production of similar future movements (Winstein, 1991). The ‘guidance hypothesis’ explains this as an overdependence, or reliance, on the guiding properties of frequent KR. This overdependence is thought to preclude the use of necessary information needed for skill performance (such as inherent feedback) during retention and transfer tasks when KR is not available (Lai & Shea, 1998; Winstein, 1991).

Several studies with similar experimental set ups requiring lever arm movement to reach varying targets and different levels of feedback followed. The results were somewhat mixed, but generally provided support for the guidance hypothesis and the understanding that practice with less frequent feedback
facilitates task specific learning as well as increased transfer, or generalization, for motor performance (Winstein, Pohl, & Lewthwaite, 1994; Wulf et al., 1993). To gain a more thorough understanding of these results, it will be helpful to consider the cognitive effort involved in the motor learning process.

**Cognitive effort.** Fitts and Posner describe a three-stage model of motor learning (Shumway-Cook & Woollacott, 2012) that serves to clarify the interaction of cognitive processing and skill acquisition. In the first stage, the learner is focused on understanding the task and determining the most effective way to meet the goal. This is referred to as “the cognitive stage” due to the high degree of attention and cognitive effort required. As many strategies are usually tried, performance is typically inconsistent in this stage of learning. Even so, the most dramatic skill improvement usually occurs during this phase (Schmidt & Lee, 2011). The learner moves into the second stage, “the associative stage”, once an effective strategy has been chosen. Performance improves much more slowly as small changes are made for skill refinement. An individual may remain in this second stage of motor learning for an extended period of time. The third stage is “the autonomous stage”. At this point practice is no longer necessary and the learner performs the skill essentially “automatically”. Markedly less cognitive effort is required and the individual can attend to task aspects beyond the movement pattern required (Schmidt & Lee, 2011; Shumway-Cook & Woollacott, 2012).

Because cognitive effort greatly impacts motor learning, decisions regarding practice and feedback conditions are best made with the changing
attentional demands of skill acquisition in mind. The Challenge Point Framework (CPF) was introduced in 2004 (Guadagnoli & Lee, 2004) with the aim of clarifying how manipulation of these factors can provide an optimal challenge point for motor learning. The underlying premise of the CPF “is that learning is a problem-solving process and that the information available during and after each attempt to solve the problem is remembered and forms the basis for learning. Too much or too little information will retard learning” (Onla-or & Winstein, 2008, p. 385).

Creating an optimal level of cognitive effort, or a just right challenge, for an individual’s information processing capabilities appears critical for successful learning. The contextual interference (CI) effect states that creating a heightened initial learning challenge with random practice of different tasks, rather than blocked practice of the same task, results in better performance during transfer tests (Shumway-Cook & Woollacott, 2012). A recent study (Wu et al., 2011) investigated the combined effects of CI and augmented FB. College students were asked to move a lever arm, similar to the task previously described (Winstein, 1991), to match four different target patterns. A shield was in place so the participants could not see their arm. Augmented FB was presented on either an every trial (100%) or 60% (faded) frequency schedule during random and blocked practice. Those in the random practice group performed better than those in the blocked practice group, regardless of feedback frequency provided. The authors concluded that the combination of these two practice conditions to increase cognitive effort did not increase learning as measured by retention and transfer tests. The cognitive effort demand created with random practice (high CI)
had a greater impact on motor learning than did the faded frequency FB condition. The findings provide support for the CI effect and contradictory information about the optimal frequency of augmented FB, indicating that further research is needed for a true understanding of the impact of cognitive effort and application to clinical practice.

Providing instruction or information regarding task performance, and anticipating positive results, assumes that the individual has the capacity to process the information. Studies have demonstrated that explicit information prior to movement execution interferes with motor sequence learning in individuals with unilateral brain damage such as a stroke. It is likely that the processes responsible for utilizing (intrinsic) feedback for motor skill development are disturbed by the explicit information. It is possible that differing forms of augmented FB are needed (Boyd & Winstein, 2006; Winstein et al., 1999).

A systematic review of how feedback supports relearning and motor movements of the hemiparetic arm post-stroke (Molier, Van Asseldonk, Hermens, & Jannink, 2011) provides some support in this area. The review included 23 studies investigating various aspects (nature, timing, frequency) and types (visual, auditory, sensory) of feedback. Augmented FB was found to enhance the learning process when added to traditional rehabilitation exercises. Findings support previous knowledge: provision of increased feedback, either during the task or with increased frequency, interferes with skill acquisition for subjects without neurological deficits, but has potential benefits for individuals post stroke. The range of methodologies included in the review did not allow for
the presentation of specific recommendations, although overall data provided support for the use of augmented FB (KP), auditory FB, and combined sensory and visual FB.

**Visual feedback.** It is commonly understood that, when available, vision dominates other sensory input. In fact, some research suggests individuals engage in continuous visual processing that aids movement correction in some manner, with only a minimal attention requirement (Proteau, Roujoula, & Messier, 2009). Practice specificity, or the match between conditions of practice and performance, is especially critical with respect to available visual FB (Gordon & Magill, 2011). In general, if visual FB is provided during practice, performance during retention and transfer tests will be best with the same visual FB available. When visual FB is provided during practice, but not during retention and transfer tests, performance deteriorates.

In one experiment (Proteau, Marteniuk, & Lévesque, 1992), participants extensively practiced an aiming motor task either with vision of their hand and the target or with vision of the target only. Following the practice sessions, vision of their hand and the target was available to both groups during retention and transfer tests. For the participants that had visual FB added during transfer (but not available during practice), performance was found to decrease. Further evidence suggests that providing augmented visual FB (i.e., real time movement trajectories), in addition to normal vision, during the learning of a bimanual task is detrimental for the transfer of skill performance to varied environmental circumstances (Puttemans et al., 2004). Collectively, findings imply that certain
strategies are developed with visual support during practice. These strategies are thought to be stored internally as a visual representation that does not prove useful if the original source of feedback is not available during retention or transfer tests, thereby degrading performance (Proteau et al., 1992; Wierinck et al., 2005). Performance is optimized when the conditions of the transfer task require the same sensorimotor representation as used/learned during practice (Schmidt & Lee, 2011).

This need for the original source of feedback implies that learning involves a specific sensorimotor representation integrated with motor movements. Evidence of neural activity and reliance upon visual FB beyond the duration of practice sessions has recently been validated through fMRI imaging (Ronsse et al., 2011). Participants practiced a novel, bimanual motor task with augmented FB of either visual input or auditory pacing. The group with visual support had increased brain activity in sensory specific areas during practice, as well as after the augmented FB was no longer available. Individuals provided with auditory augmented FB had less neural activity, particularly in areas related to cognitive and sensory aspects of motor learning.

Motor Learning and Typically Developing Children

Up to this point, research findings presented have been relative to motor learning in adults. Some general understandings about practice are especially pertinent when considering how to structure practice for enhanced learning in children. In adults, variable practice supports learning of the practiced skill and the ability to adapt to different or novel performance conditions. Blocked practice
(low CI) produces better performance during practice, while random practice (high CI) produces better performance during transfer tests. The match between practice conditions and where the skill will be performed should be taken into consideration, particularly with respect to the sensory, perceptual, and visual information available during practice (Gordon & Magill, 2011).

While it is understood children learn differently than adults, much less evidence exists to inform practitioners about strategically structuring motor skill learning. In comparison to adults, children are able to process a lesser amount of information and have decreased attention skills. These contribute to an overall slower processing rate. In designing optimal motor skill practice settings, principles need to be adjusted accordingly (Gordon & Magill, 2011).

Children learn new motor skills throughout their childhood. A common perception is that, if provided with numerous experiences and challenges, acquisition of motor skills will occur as a natural part of development. While this may be true, research provides insight into ways to maximize learning.

Wulf (1991) completed a study in which children (mean age of 11 years) practiced a throwing task with differing target distances and object weights. Results of the transfer test indicated that variable practice conditions produced the strongest performance during a novel task. Although random practice enhances learning for adults, findings are inconclusive for children. The learning of certain tasks or skills might prove so effortful as to overwhelm a child’s information processing capacities. When learning complex tasks, it is likely that
blocked practice enhances learning for younger/less skilled learners (Gordon & Magill, 2011; Kantak, Sullivan, & Burtner, 2008).

Substantially less information exists with regard to how feedback frequency and type impact skill acquisition for children. While the role of feedback to facilitate goal attainment and provide motivation remains the same, how this occurs is likely different. It would seem that less frequent FB would be helpful, so as not to overload a child's less capable information processing system. Findings of a 2008 study indicate otherwise. Important differences between adults and typically developing children in the use of augmented feedback for motor skill acquisition were demonstrated (Sullivan et al., 2008). This work evaluated the effect of reduced feedback frequency on motor learning of a discrete arm movement task. In the study, children (mean age of nine years) were assigned to one of two groups. One group received feedback about performance error after every arm movement (100% feedback frequency). The other group received reduced feedback (62% feedback) that was faded over the course of the four blocks of practice. Practice took place on the first day with a retention test completed the following day that included trials without feedback, and a reacquisition test with feedback re-introduced. Data analysis suggested that there is a critical point when feedback reduction interferes with motor learning in children that is not demonstrated in adults. It seems that typically developing children need longer periods of practice with more frequent feedback compared to adults before feedback is reduced during practice (Sullivan et al., 2008). Overall, for children, “it appears that age, task difficulty, and existing skill
level all contribute to the potential success of skill acquisition following practice” (Kantak et al., 2008).

**Motor Learning and Children with SHCP**

Children with CP are able to improve motor function with time and practice. Studies have shown that motor learning may be a slower process, but extended practice leads to improvement in grasp/object manipulation, in hand manipulation, and postural control. Functional and task oriented treatment approaches with adequate intensity have the potential for improving motor function (Gordon & Magill, 2011).

A study by Smits-Engelsman, Rameckers, and Duysens (2007) sought to determine whether poor performance (precision) on motor learning tasks was a reflection of impaired motor output or cognitive control processes. Children were engaged in a simple motor task of moving a puppet. Measurements of movement accuracy and speed were analyzed. Results comparing children with SHCP to a control group showed reduced motor output by their non-preferred hand, but similar ability to control their preferred hand and similar response to task difficulty. This particular experimental setup, with a simple movement task, clarified that motor output impairments (seen primarily in the non-preferred hand results), rather than cognitive processes, interfered with performance.

It is likely that the motor learning process is further complicated by potential sensory impairments that may diminish FB and impact the use of information in creating an internal model of movement (Gordon & Magill, 2011). Studies investigating how children with CP use visual/somatosensory information
while learning motor tasks can further aid therapists with the creation of appropriate interventions.

Verrel, Bekkering, and Steenbergen (2008) investigated eye hand coordination during an object transport task in adolescents with SHCP. They found increased visual monitoring of the affected hand, possibly indicating the use of a visual compensatory strategy due to sensorimotor impairment. A similar significant difference was not indicated for the less affected hand. Research completed by Wingert et al. (2009) provide related findings indicating vision of limbs improves movement accuracy in individuals with mild diplegic and hemiplegic CP. Researchers found proprioception deficits interfere with movement learning and performance accuracy, but optimization of vision as a compensatory strategy supports children's performance, especially during early practice.

Few studies have investigated the effect of augmented feedback on motor learning for children with CP. In one study, children with either diplegia or quadriplegia were able to learn a novel motor skill with the support of practice and feedback (KP) (Thorpe & Valvano, 2002). Those who practiced with both KP and the use of a cognitive strategy (mental practice) demonstrated better performance than children who practiced without KP or with KP alone.

Further research specifically addresses the use of visual FB and its' ultimate result on movement and motor skill acquisition. Improvements in performance attributed to the use of visual FB have been shown with concurrent, split screen feedback while completing a reach and point task (Larson & Surber-
Berro, 2006) and mirror FB during bimanual movement (Feltham et al., 2010). Suggested explanations of the positive results of these studies center around the idea that visual feedback compensates for diminished sensory information leading to a reduction in effort and improved functional performance (Feltham et al., 2010; Larson & Surber-Berro, 2006; Shumway-Cook & Woollacott, 2012).

A study investigating the impact of different feedback frequencies (0%, 50%, 100% KR) on the ability of children with SHCP to learn a dart throwing skill yielded unanticipated results (Hemayattalab & Rostami, 2010). Visual FB (re: accuracy) was provided to children on the dart screen. In contrast to findings for children presented earlier, results match previous findings for adults. Children in the 100% FB group had the best performance during acquisition. Conversely, during retention tests, the 100% FB group had the weakest performance during retention, and those in the 50% FB group performed the strongest, indicating the 'most' learning had occurred. The authors concluded that too much FB is detrimental to learning for children with SHCP.

It seems absolute conclusions regarding the use of visual FB during manual motor skill tasks have not been empirically determined. Given the important connection between visual FB and motor skill acquisition, particularly for children with CP, continued research will further clarify results and detail implications for intervention methodology.

**Effectiveness of Occupational Therapy for Children with SHCP**

Limb spasticity and difficulty with motor activity can limit a child's opportunity to participate in and experience everyday life. A large part of
rehabilitation in children with CP is designed to help them “learn” motor skills to increase independence with functional tasks associated with daily life, such as self-care, school, and play.

Motor learning principles have the opportunity to inform pediatric occupational therapy practice, although explicit use and documentation is not prevalent (Zwicker & Harris, 2009). Improvements observed during therapy sessions can be seen as analogous to improvement during the acquisition stage. The ultimate goal is to apply motor learning strategies that enhance generalization and/or transfer of learning beyond the intervention (Levac, Missiuna, Wishart, Dematteo, & Wright, 2011).

Earlier portions of this review describe outcomes of motor learning secondary to research and factors manipulated in lab settings. A review of current applications for children with CP within occupational therapy practice follows.

The recently published Focus on Function study (Law et al., 2011) presents findings that child-focused therapy and context-focused therapy approaches are equally effective. Researchers compared outcomes of two treatment groups. The child focused therapy group emphasized changing impairments and improving children’s skills and abilities through practice of functional activities. The context focused therapy group focused on changing only the task and/or the environment, not the child. Sessions included practice of functional tasks in natural environments when possible (e.g. home, preschool). Similar gains were found with both intervention styles. These findings provide
strong support for matching an intervention approach to the needs of the child and their family. A second study investigated the impact of intensive group therapy sessions (3 hours a day, 5 days a week, for 3 weeks). Interventions emphasized goal-directed, activity-focused therapy within the children’s everyday environments. Improvements in basic motor abilities and self-care ensued (Sorsdahl, Moe-Nilssen, Kaale, Rieber, & Strand, 2010).

Two studies address the success of in-home intervention methods (Golomb et al., 2010; Novak et al., 2009). The first, a randomized, controlled trial, found evidence of improvements in function, parent satisfaction, and quality of movement following the completion of an 8-week occupational therapy home program (Novak et al., 2009). An occupational therapist met with the family for 3 visits (initial, 1 and 3 months) to develop customized goals, a treatment plan, provide parent education, and upgrade/downgrade or modify activities as necessary. Therapeutic activities were implemented an average of 17.5 times per month for an average of 16.5 minutes per session. Improvement in some areas was noted at 4 weeks, but 8 weeks of intervention was required for significant effects on quality of upper limb skill (facilitation of motor change).

It is important to highlight that the previous 3 studies all had a collaborative goal setting component. This element seems critical, not only as a measurable outcome, but to ensure that the focus of intervention is meaningful for the child in their everyday setting.

A second in home intervention study reports results from a tele-rehabilitation pilot project indicating a potential new role for occupational therapy
(Golomb et al., 2010; Gordon & Magill, 2011). Three adolescents with hemiplegic CP practiced finger and hand movements via a remotely monitored virtual reality videogame. Improved hand function (ability to lift objects and finger ROM) was accompanied by preliminary findings of functional motor cortex changes evidenced by fMRI.

Aside from the studies above, the majority of motor learning intervention studies with children with CP focus on the use of constraint induced movement therapy (CIMT). The goal of CIMT is to encourage the child to use the more affected UE with massed practice of therapeutic tasks, while the less affected limb is constrained in some manner. Current systematic reviews find evidence that CIMT fosters improved UE performance in children with SHCP, but further high quality research is needed to clarify specific protocols (Hoare, Wasiak, Imms, & Carey, 2007; Huang, Fetters, Hale, & McBride, 2009).

These findings, as a whole, present the beginning translations of understandings about motor learning into clinical practice. While further research will undoubtedly clarify intervention methodologies, it is apparent that improvements in motor abilities and functional performance of children with CP result from their participation in occupational therapy.
References


