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The Effect of Extended Practice on EMG, Kinematics and Accuracy in Dominant and Non-dominant Dart Throwing

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Abstract

The question of whether dominant and non-dominant limbs are controlled by the same motor program in throwing tasks has not been clearly established. Prior research has been limited by a number of factors, including evaluations based on a small number of trials. The present study evaluated subjects over a course of five days of dart throwing using both their dominant and non-dominant limb. The variables of assessment focused on were average velocity of the throw, the angle at release, accuracy and the magnitude of EMG co-contraction over practice. The non-dominant limb was found to be significantly less accurate ($p = 0.001$), less consistent ($p < 0.001$) and produced higher velocity throws ($p = 0.001$) than the dominant limb over a total of 447 practice trials per limb. Co-contraction between agonist and antagonist muscles over the course of practice was not found to change substantially. Thus, this study supported that dart throwing is controlled by the same motor program and that the changing of limb or muscle group selection for the task is simply a parameter change.

Introduction

When we think of most physical movements, they are often associated with a preferred limb or dominant side of the body. To most of us, the thought of switching a movement to the non-dominant side is often challenging and requires more conscious thought. However, it is interesting that in theory when a movement is made, regardless of which part of the body is performing it, the same motor program from our central nervous system is in play. The concept of a motor program is somewhat abstract in that it is a stored memory of a general class of movements that the human body can perform. In order for one of these programs to become functional; however our nervous systems must provide the information about the parameters of the movement in our particular situations. Interestingly enough, which limb or group of muscles that will perform the task is simply a parameter of this overarching motor program. Therefore, a task like dart throwing with a non-dominant limb should be relatively “easy”.

Within a motor program itself there are features that are relatively fluid depending on the specific parameters and then there are features that are considered to be invariant. Some of the features that do vary when changing parameters are variables such as overall time, force, specifics of kinematics and the outcome. The invariant features of the motor program are the aspects of the movement that could be expected to be similar between the performances of a dart throw with a dominant or non-dominant arm. Some of these features include the order of events, relative timing and relative force (Schmidt & Lee, 2011). The presence of invariant features have been observed in a variety of studies that noted the triphasic/diphasic muscle activity during a task when utilizing electromyography (Aggelousis, Mavromatis, Gourgoulis, Pollatou, Mallious and Kioumourtizoglou, 2001; Darainy and Ostry, 2008; Flament, Shapiro, Kempf and Corcos, 1999; Gabriel and Boucher, 2000; Liang, Yamashita, Ni, Takahashi, Murakami, Yahagi and Kasai, 2008; Lohse, Sherwood, Healy, 2012; Ludwig, 1982). The fact that the triphasic/diphasic muscle activity persists, regardless of changes in force or time parameters supports the order of events and relative timing invariant features of a motor program.

Therefore, in the present study, some predictions for dart throwing with a dominant and non-dominant limb can be reasonably made. If the same motor program is used to complete the dart throw for both arms, then it can be expected that the invariant features such as the order of events, relative force and relative time should remain constant between limbs for this experiment. One measure in this category for the present study is the co-contraction ratio and the presence of the biphasic/triphasic muscle activity. The co-contraction ratio in this case is the ratio between the triceps integral and the biceps integral of the EMG. The relative force feature suggests that the agonist should act in accordance with the antagonist in a similar ratio, regardless of the parameter applied to the motor program. Thus, the co-contraction ratios should not be significantly different between limbs. Conversely, the measures of the variable features such as the total time and total force of the motor program will mostly vary between limbs. In this case these measures will include the average velocity, angle at release, accuracy and other measures of EMG such as maximum amplitude and integral.

Along with the goal of evaluating subjects over a length of five days of practice comes the hypothesized improvement in accuracy and the decrease in co-contraction. It has been shown that co-contraction often decreases over the course of practice when acquiring a motor skill (Darainy and Ostry, 2008; Liang et al., 2008; Moore and Marteniuk, 1986). The Bernstein Perspective has described this phenomenon. This perspective explains that mentally, the body induces co-contraction in muscles in order to resolve the degree of freedom overload for the nervous system in an unpracticed movement. Therefore, over the course, of practice Bernstein suggests that there might be greater fluidity in the movement, or less freezing of the degrees of freedom, which may be described by a co-contraction ratio (Schmidt and Lee, 2011).

While changing the parameter of limb or muscle group in motor tasks might seem innocuous, it might be for this reason that few studies have taken a detailed look into the electromyographical and kinematic differences, as is the intention of the present study. As stated by Sachlikidis and Salter (2007), sport-related research concerning the non-dominant limb in motor skills is insufficient. The current knowledge is often dated or doesn’t make a clear comparison between the dominant and non-dominant limbs (Ludwig, 1982). However, the limb parameter change could prove to be invaluable for the study of motor learning as it provides the opportunity for researchers to induce the development a skill in their adult participants. Another limitation of the current state of knowledge concerning arm related research, especially focusing on EMG, is the brevity of both the number of trials and the number of days subjects practice. While this may be a matter of electromyography restriction or simply convenience, many studies ask subjects to perform a certain number of arm related laboratory tasks within a single day (Aggelousis et al., 2001; Darainy and Ostry, 2008; Engelhorn, 1987; Flament et al., 1999; Heise, 1995; Liang et al., 2008; Lohse et al., 2010; Ludwig, 1982; Sachlikidis and Salter, 2007). There are few that evaluate subjects over the course of three or four days (Didier, Li and Magill, 2013; Gabriel and Boucher, 2000). Some studies have also evaluated subjects on as few as 40 or 55 trials (Heise, 1995; Sachlikidis and Salter, 2007).

Methods

Participants

Data were collected from 4 male undergraduate students at the University of Colorado at Boulder who volunteered to participate in this experiment. All of the subjects were right hand dominant and had light to moderate experience throwing darts with their dominant limb. None of the subjects reported having any substantial practice dart throwing with their non-dominant limb. All subjects gave informed consent in accordance with University of Colorado at Boulder's IRB.

Materials & Measurements

The subjects were prepared for the experiment with EMG electrodes, and given instruction on posture, while also being told to aim for the bullseye with an elbow extension driven throw in the sagittal plane. The experimenter first cleaned their skin with alcohol preparatory wipes and then placed a total of 5 electrodes on each arm of each subject. Two of which were placed on belly of the triceps brachii muscle (agonist) and another two were placed on the belly of the biceps brachii muscle (antagonist). The final electrode was placed on the bony protrusion of the elbow, the lateral epicondyle of the humerus, as a source of ground signal. The wireless EMG transmitter called the Bionomadix system from BioPac Inc. was then strapped onto the subjects arm and the wires were connected to the electrodes accordingly, as seen in Figure 1. Subjects were asked to stand at a distance of 2.37 m from the competition bristle dartboard, which was mounted at 1.73 m above the floor and threw regulation steel tip darts (22 g) in sets of three. Subjects were instructed to keep their body perpendicular to the line of sight from the high speed camera that was positioned on a table across from the marked throwing line. The darts all had similar size and material flights, but were different colors so as to identify each throw with its specific accuracy, kinematic and EMG measure.

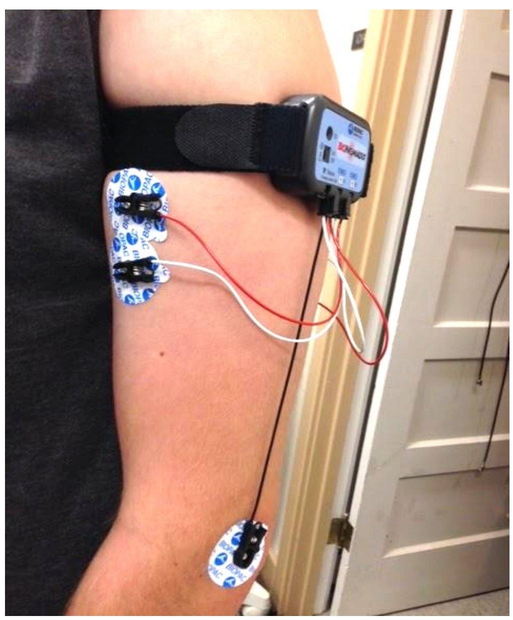

Figure 1. Example of EMG electrode and transmitter application prior to experimental dart throws.

Dart accuracy error was measured on as if the dartboard were a X-Y coordinate system with the bullseye at (0,0). An X-error and a Y-error were measured in cm. From the error scores two error scores, radial error and variable error, were calculated in order to assess the subject's performance. Radial error was calculated with the Pythagorean Theorem in order to find the diagonal distance of the dart from the bullseye (RE=SQRT((X-Error^2)+(Y-Error^2))). The variable error was then calculated with these same X and Y errors in order to assess the inconsistency of the throws from each of the subjects own mean value (VE=SQRT(Σ(x_i-M)^2/n)).

The Bionomadix EMG wireless reciever was connected to a PC where the data were collected with the software Acknowledge also from BioPac Inc. The software collected data at 2000 Hz from the surface electrodes on the subject's muscles. During analysis any zero offset of the measurement as removed, the signal was rectified and was smoothed with a five-sample moving average filter. Then measurement were taken simultaneously from both the triceps (agonist) and biceps (antagonist) during the length of time of the first agonist burst by estimating a start point when the signal rose above the baseline and terminating the measure as the signal returned mostly to the baseline level of activity. The measurements taken include the integral and the maximum amplitude of each of the muscles as well as the duration of the triceps burst. It is important to note, especially with the maximum measures that this analysis revealed only the maximum within the time frame, not simply for the entire muscle activity series, as demonstrated in Figure 2. The integrals from each of the muscles were then used in a ratio of agonist to antagonist to compute the amount of co-contraction occurring during throwing action.

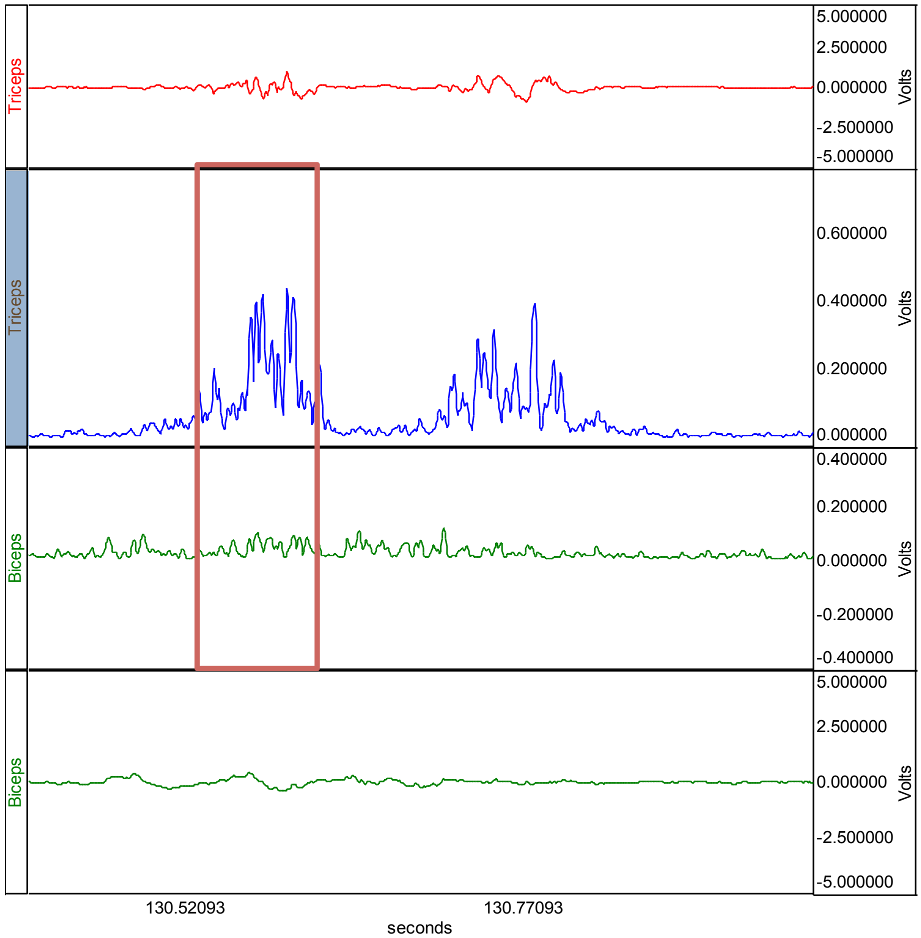

Figure 2. This is an example of EMG signal including raw signal (channels 1 and 4) and signal after modification for analysis (channels 2 and 3). Notice that the modification involved the magnification of the raw signal. The red box indicates the approximate duration of time that the analysis utilized. This is a demonstration of the triphasic muscle activity observed in this study because there are two bursts of the agonist muscle, which are bisected by the antagonistic activity.

The video from the throws was captured at 210 frames per second using a slow-motion capable camera mounted on a level tripod. The video was then analyzed using Kinovea version 0.8.15, free motion analysis software, in order to find the average velocity of the dart as it was thrown from elbow flexion to the point of release as well as the elbow angle at the point of release. The length of each subject's upper arm was used as a length calibration at the beginning of each video and thus each set of three darts. The collected frame rate was entered as a time calibration. The dart was then tagged and the path tracked for distance in meters while the stopwatch recorded the length of the tracked path in seconds, both of which were used to calculate average velocity of the forward motion of the dart throw. Marking the central locations of the subject's wrist, elbow and shoulder were used with the Kinovea angle tool when measuring the angle of the elbow at release. All video measurements were made by a single researcher to reduce variability in technique.

All accuracy, EMG and kinematic data were run through SPSS statistical software. Repeated Measures ANOVA were used in order to compile means and obtain tests of within subjects' effects for significance. The ANOVA was structured as a 2 x 3 x 2 (limb x day x block) for the EMG data and as a 2 x 2 x 2 (limb x day x block) for the kinematic data. EMG data was assessed for days one, three and five and kinematic data was assessed for days one and five.

Figures 3 & 4. This is a sample of a still frame of the Kinovea kinematic analysis of a dominant (left) and non-dominant (right) dart throw.

Design

The measurements were taken from subjects on five different days with a range of zero to three days between each day of measurement. On days one, three and five, subjects threw prepractice, practice and postpractice blocks of darts, first with their dominant limb and then with their non-dominant limb. The pre- and post- blocks each included seven sets of three darts and each throw was assessed for accuracy, EMG, and was videotaped. During practice blocks EMG and accuracy were measured randomly, once per every three sets of darts, for a total of 57 practice throws. Overall, days one, three and five involved a total of 99 throws per arm and took about two hours for the subjects to complete. Days two and four consisted entirely of practice, again random EMG and accuracy measures were taken once per three sets of dart throws. The practice days totaled 75 throws per limb, with the non-dominant limb first and dominant limb second and took only about 45 minutes for the subjects to complete. Each subject thus completed a total of 447 throws with each arm during the course of this experiment.

Results

Accuracy & Precision

The results of accuracy were the most profound of all the measures taken in this study. The measure of the radial error from the bullseye when averaged over all four subjects showed a statistically significant effect of limb and day. The dominant limb was substantially more accurate than the non-dominant limb ($p = 0.001$) and the throws became more accurate over days of practice ($p = 0.006$). There was almost a significant effect between the pre and post blocks with a p value of 0.099. As seen in Figure 2, the subjects became more accurate at throwing nearer to the bullseye over the course of the experiment. It is interesting that the error for the non-dominant limb became nearly indistinguishable from the dominant limb in the pre and post practice blocks on day five.

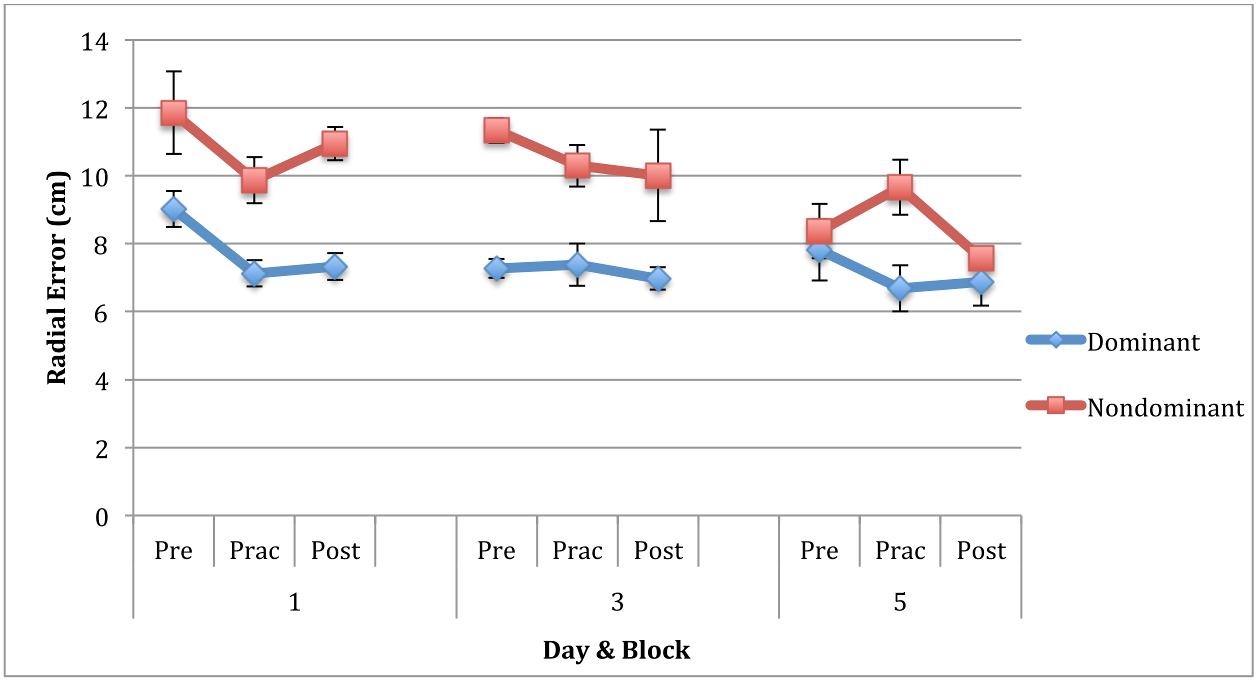

Figure 2. This is a graph of the radial error averaged over all four subjects. The dart throws with the dominant limb became slightly and gradually more accurate to the bullseye while the non-dominant limb improved more noticeably over practice.

In terms of variable error, or the precision of the throws, there was an indication of significance between the dominant and non-dominant limb as well as over days of practice. The dominant limb was far more precise than the non-dominant limb ($p < 0.001$) and the effect of practice was also influential for both limbs ($p = 0.031$), as demonstrated in Figure 3. The difference between the preliminary and concluding blocks of measurement within days one, three and five was not noteworthy in this case. Once again by day five the dominant and non-dominant limb were relatively similar in the pre and post block measurements.

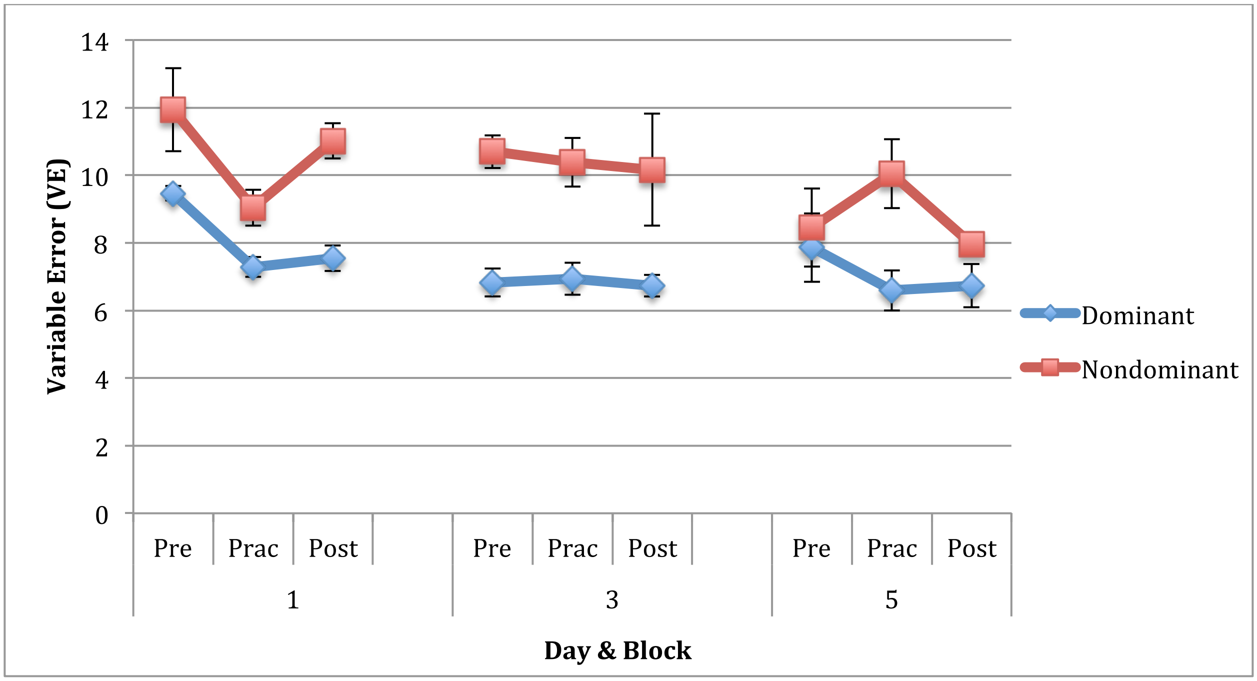

Figure 3. This is a graph of the variable error averaged over all four subjects. The dart throws with the dominant limb were less variable than those with the non-dominant limb. Both limbs became more consistent over the course of practice.

Kinematics

The kinematics measured in this study include angle at release and average velocity of the forward motion of the throw. The angle at release did not significantly change over the course of practice and was also not significantly different between limbs or blocks of practice. The overall average between all four subjects for the dominant limb was an angle of about 107.5 degrees and the average for the non-dominant limb was about 110.3 degrees. However, the velocity was markedly faster throughout the study for the non-dominant limb than was observed for the dominant limb ($p = 0.001$). There was not an effect of block or day on velocity, yet there did seem to be a slight trend toward faster velocities across the blocks and the days of measurement, as seen in Figure 4.

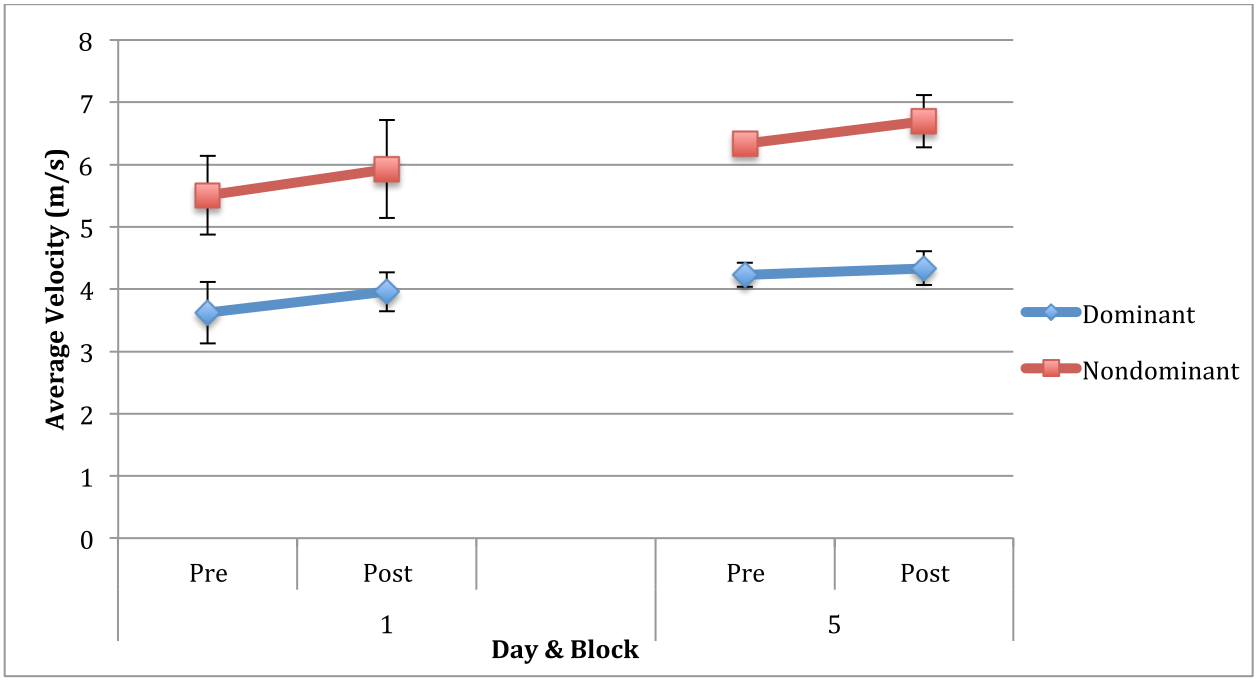

Figure 4. This is a graph of the dart velocity during the forward motion of the throw, up to the point of release averaged over all four subjects. The velocities tended to gradually increase and become less variable over the course of practice.

Co-contraction & Correlations

The co-contraction ratio between the triceps and the biceps muscle during the time frame of the first agonist burst did not change substantially over practice and was not notably different between the dominant and non-dominant limbs. The overall mean for the co-contraction variable of the dominant limb was about 3.42 while the non-dominant limb averaged about 4.53 for the. One correlation to note is the correlation between velocity and co-contraction. While this correlation does not hold any statistical weight, there is almost a significant effect of block (p = 0.06) and shows a trend of being consistently negative. Another correlation that is consistently negative is the Y-error and the co-contraction ratio. This variable consists one large correlation of -0.95 in the day one, non-dominant post-practice measurement, as seen in Table 1.

Table 1. This is a summary table of the angle at release, EMG variables and correlations between accuracy variables. The asterisk indicates that the data is based only on subjects 1 and 2. There were no significant relationships to note in these data.

	Dominant				Non-Dominant			
	Day 1 Pre	Day 1 Post	Day 5 Pre	Day 5 Post	Day 1 Pre	Day 1 Post	Day 5 Pre	Day 5 Post
Angle (deg)	105.85 ± 12.28	109.54 ± 14.57	110.09 ± 9.31	104.58 ± 8.50	107.11 ± 13.90	112.65 ± 13.49	110.52 ± 3.57	111.01 ± 8.08
Cocontraction*	3.393 ± 1.078	4.469 ± 2.629	3.321 ± 1.559	2.491 ± 1.025	4.637 ± 2.927	4.458 ± 3.097	4.769 ± 2.966	4.273 ± 2.644
Triceps Max (volts)*	0.5938 ± 0.1303	0.8090 ± 0.1427	0.7599 ± 0.3554	0.6453 ± 0.2996	0.5504 ± 0.2412	0.5043 ± 0.2273	0.5557 ± 0.3220	0.6645 ± 0.1154
Triceps Integral (volts)*	0.0192 ± 0.0089	0.0233 ± 0.0026	0.0292 ± 0.0182	0.0246 ± 0.0154	0.0218 ± 0.0129	0.0188 ± 0.0118	0.0226 ± 0.0164	0.0235 ± 0.0066
Triceps Duration (sec)*	0.1011 ± 0.0338	0.1074 ± 0.0325	0.1411 ± 0.0361	0.1367 ± 0.0288	0.1427 ± 0.0472	0.1319 ± 0.0231	0.1395 ± 0.0228	0.1492 ± 0.0011
Biceps Max (volts)*	0.2559 ± 0.207	0.2876 ± 0.2118	0.2795 ± 0.0443	0.3370 ± 0.0324	0.1624 ± 0.0682	0.1442 ± 0.0852	0.1374 ± 0.0474	0.2725 ± 0.252
Biceps Integral (volts)*	0.0071 ± 0.0060	0.0091 ± 0.0075	0.0092 ± 0.0005	0.0105 ± 0.0012	0.0060 ± 0.002	0.0057 ± 0.003	0.0054 ± 0.001	0.0082 ± 0.006
RE: Cocontraction*	−0.0287 ± 0.212	−0.03866 ± 0.111	0.0397 ± 0.0024	0.1964 ± 0.3155	0.0730 ± 0.3274	0.0032 ± 0.2645	0.3311 ± 1.0265	−0.1124 ± 0.1711
RE: Velocity	0.0203 ± 0.2821	−0.0341 ± 0.1964	0.0045 ± 0.1379	0.1001 ± 0.1717	−0.2321 ± 0.4897	−0.1928 ± 0.4436	0.0461 ± 0.4085	−0.0498 ± 0.0784
Velocity: Cocontraction*	−0.3321 ± 0.2890	−0.0103 ± 0.3054	−0.2260 ± 0.4988	−0.0229 ± 0.2205	0.1297 ± 0.2244	−0.1587 ± 0.5014	−0.0298 ± 0.3353	0.1653 ± 0.2882
Velocity: X-Error	0.0813 ± 0.2007	0.2072 ± 0.1360	0.0771 ± 0.1355	−0.0345 ± 0.2347	−0.3643 ± 0.3507	−0.0226 ± 0.3984	0.1020 ± 0.2412	0.1107 ± 0.2202
Velocity: Y-Error	−0.1653 ± 0.2325	0.0855 ± 0.0208	0.0054 ± 0.3038	0.0755 ± 0.2662	0.4205 ± 0.3674	−0.0125 ± 0.2861	0.1571 ± 0.0967	0.1310 ± 0.1679
X-Error: Cocontraction*	−0.0761 ± 0.2490	−0.1252 ± 0.1653	−0.0255 ± 0.1564	0.1707 ± 0.05443	−0.3340 ± 0.2517	0.2642 ± 0.6312	−0.1391 ± 0.2997	−0.0943 ± 0.4878
Y-Error: Cocontraction*	−0.0115 ± 0.4864	0.2037 ± 0.1897	−0.0587 ± 0.1029	0.0672 ± 0.2307	−0.0877 ± 0.2822	−0.9514 ± 1.2819	−0.0152 ± 0.1022	−0.1161 ± 0.3381

Discussion

According to the motor program theory, if the same motor program was used when completing a dart throw with both the dominant and non-dominant limb, then the invariant features of a motor program hold true. In fact, co-contraction, the measure of invariant feature in this study, was not significantly different between the dominant and non-dominant arm. In addition a biphasic and sometimes triphasic muscle activation pattern was seen in both limbs.

Both of which support the prediction of invariance of the relative features of a motor program and their insensitively to changing parameters. Also in accordance with the motor program theory, the accuracy and velocity data were significantly different between the limbs. All of which supports the conclusion that changing muscle group selection of limb of dominance is simply a parameter change of a single motor program, rather than two separate motor programs.

While the data did show a slight decrease in co-contraction over practice for both the dominant and non-dominant limb, this change might not have been as great as expected due to the limited amount of data that was obtained in this study. A co-contraction decrease over practice tends to be a gradual process by which the individual becomes more comfortable and thus natural looking when performing a motor task. Therefore it is possible that these five days of practice might not have been a clear demonstration of substantial motor adaption for either limb and thus co-contraction was not greatly reduced. Another possible explanation points to the two main limitations of this study were the number of subjects that were evaluated and the fact that the EMG measures were only valid for subjects one and two. Two subjects' EMG data was incomplete due to technical glitches. Another important thing to note is that the EMG electrodes where removed after each day of practice and replaced before the next session. Therefore, it is possible that the slight repositioning of the electrodes may have influenced these data. These limitations, especially the use of two subjects worth of EMG data, could serve as an explanation for why the correlations between the EMG and kinematic measures were so low. Another possible reason the correlations were low could have been that there was variability within and between subjects, which was negated when the averages were complied.

However, an interesting point of conversation resulting from this study is the fact that the non-dominant limb was found to consistently produce a faster velocity throw, on average. This kinematic difference between the limbs might have been a result of the subject's greater conscious attention and potentially an over compensation for lower levels of technical skill in the throw. Technical skill that may have influenced performance could have included a wrist flick or the action of the fingers at release. It is interesting to note that the greater velocity and more error prone accuracy could be a demonstration a speed-accuracy trade off in comparison to the dominant limb. This is to say that, the faster the subjects tried to throw the dart, the less accurate and consistently they performed.

While this study worked to highlight some of the weaknesses in the comprehensive understanding of kinematic, accuracy and electromyography, further study seems necessary. Future study should continue to develop a more complete understanding and comparison with non-dominant limbs or other parameters changes as a method for identifying and utilizing motor programs in rehabilitation or athletic contexts.

Works Cited

Aggelousis, N., Mavromatis, G., Gourgoulis, V., Pollatou, E., Malliou, V., & Kioumortzoglou, E. (2001). Modifications of neuromuscular activity and improvement in performance of a novel motor skill. Perceptual and Motor Skills, 93(1), 239-248.

Darainy, M., & Ostry, D. J. (2008). Muscle cocontraction following dynamics learning. Experimental Brain Research, 190(2), 153-163. doi:http://dx.doi.org/10.1007/s00221-008-1457-y

Didier, J. J., Li, L., & Magill, R. A. (2013). Environmental context affects outcome and kinematic changes at different rates during skill learning. *Perceptual and Motor Skills, 116*(3), 953-968.

Engelhorn, R. R. (1987). Effects of skill practice on electromyographic activity patterns and frequency spectra. Human Movement Science, 6(2), 117-131.

Flament, D., Shapiro, M. B., Kempf, T., & Corcos, D. M. (1999). Time course and temporal order of changes in movement kinematics during learning of fast and accurate elbow flexions. Experimental Brain Research.Experimentelle Hirnforschung.Expérimentation Cérébrale, 129(3), 441-450.

Gabriel, D. A., & Boucher, J. P. (2000). Practicing a maximal performance task: A cooperative strategy for muscle activity. Research Quarterly for Exercise and Sport, 71(3), 217-228.

Heise, G. D. (1995). EMG changes in agonist muscles during practice of a multijoint throwing skill. Journal of Electromyography and Kinesiology, 5(2), 81-94.

Ludwig, D. A. (1982). EMG changes during acquisition of a motor skill. American Journal of Physical Medicine, 61(5), 229-243.

Liang, N., Yamashita, T., Ni, Z., Takahashi, M., Murakami, T., Yahagi, S., & Kasai, T. (2008). Temporal modulations of agonist and antagonist muscle activities accompanying improved performance of ballistic movements. Human Movement Science, 27(1), 12-28.

Moore, S. P., & Marteniuk, R. G. (1986). Kinematic and electromyographic changes that occur as a function of learning a time-constrained aiming task. Journal Of Motor Behavior, 18(4), 397-426.

Sachlikidis, A., & Salter, C. (2007). A biomechanical comparison of dominant and non-dominant arm throws for speed and accuracy. Sports Biomechanics / International Society of Biomechanics in Sports, 6(3), 334-344.

Schmidt, R., & Lee, T. (2011). *Motor control and learning: A behavioral emphasis*. (5th ed., pp. 177-222, 429-459). Champaign, IL: Human Kinetics.