A Quantitative Analysis of Ground Contact Time, Impulse, and Average Force in Various Plyometric Exercises

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Abstract

Purpose:
Hurdle hops and jumping variations have long been utilized as explosive, reactive movements by strength coaches in order to prepare their athletes and optimize their rate of force production. The purpose of this study was to analyze and compare the differences in ground contact time and impulse between hurdle hops and two separate jump variations. The objective is to provide sports performance professionals with a quantitative analysis of these movements in order to enhance the quality and overall effectiveness of their training regimens.

Methods:
Eighteen Division I male ice hockey players participated in this study to assess differences in ground contact time, impulse, and average force produced between hurdle hops (18") and two jump variations: Antagonistically Facilitated Specialized Movement (AFSM) and Depth Drop Jump (DDJ). Participants were familiarized with each of the two jump variations and the hurdle hop prior to testing. Hurdle hop data was collected in two trials for each of the first and third hurdle hops. Jump data was collected in two trials for each of the three jump variations.

Results:
Three paired-sample t-tests displayed significant differences between hurdle hops (HH) and AFSM jumps in movement time (p=.000, HH=.221s±.039s, AFSM=.430s±.062s), impulse (p=.000, HH=633N*s±65N*s, AFSM=777N*s±88N*s) and average force (p=.000, HH=2905±354N, AFSM=1827±198N). Additionally, three paired-sample t-tests provided significant differences between HH and DDJ in movement time (p=.000, HH=.221s±.039s, DDJ=.367±.055), impulse (p=.000, HH=633N*s±65N*s, DDJ=768N*s±85N*s), and average force produced (p=.000, HH=2905±354N, DDJ=2115N±213N).

Conclusion:
It can be concluded that there are significant differences in the way an athlete performs a hurdle hop in comparison to the way an athlete performs an AFSM jump or a DDJ. While the total change in momentum (impulse) is greater in both of the jump variations when measured against the hurdle hops, the movement time and average force produced throughout the movement is less in the hurdle hops than in the jump variations. Sports performance professionals could use these quantified differences to appropriately cater exercises based on the desired training parameter.

Conclusion

As reflected in the results, the total impulse of both jump variations (AFSM and DDJ) was significantly higher than the total impulse in the hurdle hops. A higher impulse indicates a larger change in momentum. It appears that during the AFSM and DDJ the athletes were more focused on exerting a maximal effort in order to obtain the greatest change in momentum on each individual jump within the trial; as opposed to the hurdle hops where the athletes appear to be less concerned with this change in momentum. A change in momentum in jumping variations could originate from an immediate halting of downward momentum or a generation of upward momentum, meaning that a higher impulse does not necessarily mean a higher jump, (i.e. all things being equal, if one athlete were to start with downward momentum and jump a certain height the impulse he produces would be higher than an athlete who jumped the same height but started with no downward momentum). It can be seen, then, that the athlete that started with downward momentum had to expend more effort to halt that momentum and produce the upward momentum. This is what allows us to say that the AFSM and the DDJ required more effort per trial than the hurdle hops.

The data also revealed significantly shorter ground contact times in the hurdle hops as compared to either jump variation. These shorter ground contact times most likely contributed to the smaller amount of total impulse seen in hurdle hops. An advantage to these short ground contact times, though, is that they most closely mimic the ground contact times that are experienced in a number of sports[1].

The last variable assessed was average force produced throughout the movement and was calculated by dividing the total impulse by ground contact time. Hurdle hops showed significantly higher average forces than either of the jump variations. Again, the average forces produced during hurdle hops more closely replicate the average forces seen in on field movements[1].

It is hypothesized that all of the differences seen between the two jump variations and the hurdle hops are closely related to the joint angles seen in each respective movement. With hurdles of only eighteen inches the athletes were able to achieve the height needed to clear each hurdle without leaving an advantageous lower extremity position. This allowed them to keep ground contact times short and thus average forces high. The AFSM and DDJ, however, forced athletes to drop into a disadvantageous position to generate a large change in momentum to reach a maximal jump height. These disadvantageous positions were evidenced by longer ground contact times and thus lower average forces.

Sports performance professionals could use the results of this study to more intentionally select specific movements based on the phase that their athletes are progressing through. For example, due to the substantially shorter ground contact times yielded by the hurdle hops, it may be more beneficial to incorporate these types of movements into a speed-strength or realization phase as opposed to a hypertrophy or more strength oriented time period. On the other hand, the maximal effort acquired from AFSM and DDJ may be better implemented into a strength-speed phase.

Introduction

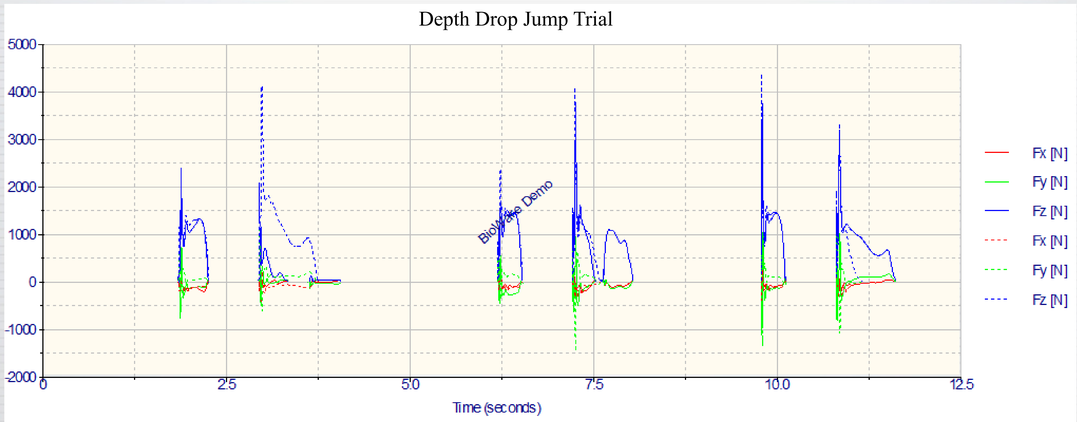
Many of the major sports in the world involve speed and change of direction. With this in mind, it is the goal of sports performance practitioners to improve these qualities in their athletes. Plyometric means have been implemented in training protocols in an attempt to maximize an athlete's ability to utilize the stretch-shortening cycle and, in doing so, produce high amounts of force in short amounts of time[1]. In other words an athlete yielding a higher rate of force development is the athlete with an advantage when it is most crucial during competition[4,6].

Furthermore, rate of force development is an essential component in the change of momentum, or impulse, that an athlete is capable of generating. Physically, by definition, impulse is the change in momentum or the average force multiplied by the time taken for force to be produced. Consequently, within the world of athletics, calculating and monitoring impulse provides an effective tool in quantitatively measuring an athlete's change in direction. One of the ways in which this is made possible is by utilizing piezoelectric force plates that are specially designed to gauge a three-dimensional force based on the electric charge that is accumulated due to some form of mechanical stress. From the force-time data accrued by the force plates, impulse can be calculated by taking the integral of the force with respect to time.

The total impulse an athlete produces at any given time is primarily comprised of two different variables: time and average force. Due to the nature of the direct relationship present between impulse and time, it is mathematically clear and concise how manipulating the time variable will affect overall impulse. For example, generating an arbitrary level of force for a given amount of time will yield a higher impulse than if that same level of force was produced for a shorter duration of time. Although an increase in time can lead to an increase in impulse, this relationship is essentially worthless when applying it practically to athletics. As a result of the necessity for fast, efficient movements in the world of sports, the latter component of impulse is what coaches desire to manipulate through the venue of training in order to elevate the athlete's change in momentum. Average force is a much more realistic, applicable variable to influence because of the time restrictions present in sports. Due to the fact that athletes do not generally have time as a commodity during their respective competitions, rate of force development is an imperative factor when considering average force and its impact on impulse.

As alluded to above, plyometric means are primarily utilized to train an athlete to produce a high amount of impulse in a short amount of time. A large impulse in a short amount of time indicates a large force produced and, consequently, a fast change in direction. This concept can be illustrated with the example of a running back moving at full sprint, stopping abruptly, and then accelerating quickly in another direction. Over the years, sports performance practitioners have conventionally utilized hurdle hops as one of the exercises in their training regimens in an attempt to target and optimize the athlete's ability to create a high impulse in a short amount of time[1]. Furthermore, they have also implemented depth drop jumps and countermovement jump variations into their programs in order to train their athletes in a plyometric fashion[1,2,6].

Ultimately these researchers desire to analyze the discrepancies in total average force, ground contact time, and impulse between hurdle hops and two different jump variations. An improved understanding of these differences could enable sports performance professionals to select movements that will optimally train the desired parameter.



Results

Three paired-sample t-tests displayed significant differences between hurdle hops (HH) and AFSM jumps in movement time (p=.000, HH=.221s±.039s, AFSM=.430s±.062s), impulse (p=.000, HH=633N*s±65N*s, AFSM=777N*s±88N*s) and average force (p=.000, HH=2905±354N, AFSM=1827±198N). Additionally, three paired-sample t-tests provided significant differences between HH and DDJ in movement time (p=.000, HH=.221s±.039s, DDJ=.367±.055), impulse (p=.000, HH=633N*s±65N*s, DDJ=768N*s±85N*s), and average force produced (p=.000, HH=2905±354N, DDJ=2115N±213N).

Methods

A total of eighteen current University of Minnesota men's hockey players were utilized as participants in this study. Data were collected at various points throughout the accumulation phase of a triphasic mesocycle at the convenience of both the strength coach and the athletes. Each day the hockey players came in at the same time and were led through identical dynamic warm-ups by the coaches. Experimental trials were conducted during the course of the workout as a facet of a French contrast circuit. Players were told prior to the workout whether they would be performing hurdle hops or the two plyometric jump variations as part of this contrast circuit.

On the days in which hurdle hops were performed, hurdles were set to a height of eighteen inches with four feet separating each hurdle. Four hurdles were utilized to allow athletes to perform four different jumps, three of which were considered reactive (excluding the first jump). Two trials were taken on the first reactive jump and two trials were taken on the third reactive jump. For these hurdle hops, athletes were instructed to perform jumps as rapidly and explosively as possible. Data were collected on Bioware Software using Kistler piezoelectric force plates. Two force plates were utilized throughout this process, one in which was paired with the left foot for all trials and the other, which was paired with the right foot for all trials.

On days in which the athletes were not performing hurdle hops as a component of their contrast circuit, they instead performed two different plyometric jump variations. These two jumps were chosen because their simplicity and familiarity allowed the athletes to primarily focus on producing a maximum effort rather than executing a novel movement. The first jump the athletes performed was an antagonistically facilitated specialized movement (AFSM) jump in which they were instructed to physically pull themselves down to an explosive position and then immediately jump as high as possible. When performed correctly, this type of explosive movement involves the athlete's feet leaving the ground on the way down due to the pulling of the hamstrings. The second jump variation was a box drop jump where the athletes were instructed to walk off of an 8" high box and pull themselves to the ground in a similar fashion as the AFSM jump. An 8" box drop was decided on due to the fact that it provided sufficient variation from the AFSM jump and therefore was worth looking into additionally. Furthermore, due to the unknown nature of the athletes' capabilities in terms of being able to absorb and transfer force, anything beyond 8" served as potential for injuring the athletes. Once athletes hit the force plates in a ready position, they then proceeded to explode upwards and jump as high as possible. Athletes performed two trials of each jump variation, and for each of these two trials, the athletes performed three jumps.

Trial data were processed and displayed in the form of force-time graphs, which were then exported to Microsoft Xcel in order to numerically analyze the data. Each jump was analyzed for movement time, total impulse, and average force. Of the six jumps performed for each jump variation (AFSM and DDJ), the two best, as judged by the highest average force, were taken for statistical analysis. Similarly, the best 1st hurdle hop jump and the best 3rd hurdle hop jump were taken and grouped together for analysis. Movement time was determined at the point in which the total force initially rose above 15 Newtons and ceased when the force dipped below 15 Newtons. This allowed for a precise measurement of movement time across all trials primarily due to the fact that it cut out some of the forces due to vibrations in the room that the force plates were detecting. Total impulse was calculated by taking advantage of the trapezoidal rule in order to approximate the integral of the total force with respect to time from the beginning of the movement time to the end of the movement time for each jump. Average force was then found by dividing total impulse by the movement time. Each trial was then sorted and organized in an Xcel file in preparation for it to be imported to SPSS.

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