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An Advanced Look at the Mechanics of Hopping

INTRODUCTION

Perhaps one of the most common physical activities seen from those in the playful, care-free years of childhood is hopping. While hopping isn't necessary for activities of daily living, children find much enjoyment in using their imaginations to pretend they are animals that primarily use hopping as a means of locomotion (i.e. grasshoppers, rabbits, frogs, kangaroos, etc.). Seeing the value of teaching children early on about health awareness, physical educators even incorporate this universally loved movement among those of the younger population into their lesson plans with activities such as "leap frog" and other physically-engaging games. More evidence of the importance to educate children on leading a healthy lifestyle is seen by the American Heart Association, which is active in elementary schools across the United States through a program known as Jump Rope For Heart. This program promotes physical education and provides children with knowledge of heart disease and stroke while raising funds for cardiovascular disease research, stroke research, and health education.[1] Hopping can be thought of as a mild form of jumping, and therefore, is not a difficult movement to perform; however, it is possible to hop in such a way that could potentially be unbeneficial over time and lead to chronic injury. In this analysis, we will observe and analyze the movements associated with the physical activity of hopping.

PHASES OF HOPPING

Starting Phase

Throughout the entire action of hopping with both feet, several muscles will be involved in concentric, eccentric, and isometric contractions, along with relaxations of the opposite muscles. Additionally, the roles of the various muscles involved will change between agonist and antagonist depending on the joint action. In order for children (or anyone for that matter) to perform a hop, they must begin in a squatting position. This position creates the potential energy that will eventually be transferred into kinetic energy and used as the power source for allowing the body to leave the ground. To reach this initial stage of a hop, an individual will leave a common standing stance by moving their gluteus muscles posteriorly in the sagittal plane with hip flexion. To accomplish this, the hip flexors act as the agonistic muscle group by contracting and bringing the upper body anteriorly in the sagittal plane, while the hip extensors (the antagonistic muscle group) relax, or elongate. The primary hip flexors include the iliopsoas, pectineus, rectus femoris, and sartorius, while the gluteus maximus, biceps femoris, semitendinosus, semimembranosus, and external rotators comprise the primary extensors of the hip.

Though the hip has entered into flexion and the line of gravity travels through the back, the torso is able to remain erect in a hyperextended position because of the several extensors in the back, known as the erector spinae muscle group (illiocostalis, longissimus, and spinalis), the transversospinalis muscle group (semispinalis, multifidi, and rotatores), and the interspinales muscles. There are more posterior trunk muscles within the body, but these are the ones that are primarily involved in (hyper)extending the trunk, as is needed to get into a squatting position. In order for the trunk extensors to perform their role in the body, their antagonistic muscle groups must be elongated. The muscles that will act antagonistically to the trunk extensors include the rectus abdominis and the internal and external obliques.

The first movement of hip flexion seen within the Starting phase of hopping is immediately followed by actions of the rest of the body. More specifically, we see that the individual will simultaneously flex their knees, elbows, and fingers and dorsiflex their ankle. In this position, the individual's center of mass is now lower to the ground than when the individual was standing, meaning they now have more stability. This is good since they are about to apply force to the ground and be lifted up off from it.

The prime flexors of the knee include the hamstring muscle group, the popliteus, and the gastrocnemius. The hamstrings are made up of the semimembranosus, semitendinosus, and biceps femoris (mainly the short head will perform knee flexion). As these muscles contract to bring the knee into flexion (agonist), the muscles of the quadriceps (agonistic) will be elongated to allow this range of motion. These agonistic muscles, which perform knee extension, are the rectus femoris, vastus medialis, vastus intermedialis, and vastus lateralis.

In considering the flexion of both elbows, we can denote concentric contractions from the biceps brachii muscle, the brachialis muscle, and the brachioradialis muscle. At the distal end of the forearm is the hand, which contains the thumb and fingers. When hopping, along with elbow flexion, it is typical to see an individual also flex all their thumbs and fingers (as if balling their hands into fists). To achieve this, of course, the individual will need muscle contractions. There are both intrinsic and extrinsic muscles involved in contraction to cause thumb and finger flexion. For the thumb, the extrinsic muscle is the flexor pollicis longus, and the intrinsic muscle is the flexor pollicis brevis. Since the action of opposition is the combination of flexion and abduction, it is also likely that the individual will use their opponens pollicis muscle as they ball their hand into a compacted fist. For the four fingers, there are more muscles recruited for motion. Extrinsically, there is the flexor digitorum superficialis and the flexor digitorum profundus, and intrinsically, the flexor digiti minimi and the lumbricales (only considering its role in flexion of the metacarpophalangeal joint). So in quick review of the observed motions of the arms, we see that the individual flexes both their elbows and all fingers and thumbs. This is done instinctively because such combined joint actions actually make the physical activity of hopping easier. From a biomechanical perspective, the action of bringing the arms closer to the center of mass of the individual reduces rotational inertia, which, according to John McLester and Peter St. Pierre, is the resistance of an object to having its state of angular motion changed.[2] Regarding rotational inertia, both the mass and distribution of mass are contributors. Since acceleration is proportional to the applied torque and inversely proportion to the rotational inertia of the individual's arms, by lowering the rotational inertia of the arms, less torque needs to be applied to produce acceleration. In layman's terms, this means there will be less resistance that the body has to counter in order to perform a hop. This is why professional runners will bring their knees up high throughout their strides, why it is easier to perform jumping jacks with bent arms, and why ice skaters are able to increase the velocity in which they spin when they bring their limbs close to their body.[2]

Another simultaneous action we can observe is the extending of the neck into hyperextension in order to keep vision straight ahead. In keeping the line of sight forward, the individual is more easily able to maintain balance, since vision is one of the three contributing factors to balance. To hyperextend their neck while squatting down, an individual will use some of the muscles that have already been mentioned in trunk extension, as well as some that haven't been mentioned yet. The muscles responsible for (hyper)extending the neck are the erector spinae muscles (illiocostalis, longissimus, and spinalis), the splenius capitis muscles, and the splenius cervicis muscles. Both the splenius captitis and splenius cervicis originate from the vertebrae, but they both do not remain on the spine for insertion. As their names suggest, the splenius capitis muscles will move the head because of their attachment to the mastoid process, while the splenius cervicis muscles remain attached to the (cervical) vertebrae and only move the neck into extension. Also, there is a cluster of small muscles underneath the base of the skull posteriorly that will only extend the head and work alongside neck extension known as the suboccipital muscles; these include the superior and inferior obliquus capitis and the major and minor rectus capitis posterior as well.[3]

The final motion noticed in the Starting phase of hopping is dorsiflexion of both ankles. The primary muscle causing this action includes the tibialis anterior; the extensor hallucis longus and extensor digitorum longus are two additional muscles that will assist in dorsiflexion. The ankles will be dorsiflexed to allow the body to drop down low. Also notice, though, that the degree of dorsiflexion will continue to increase past the position that allows for squatting down; this continual action of dorsiflexion results in the body of the individual to lean forward until they leave their base of support. As the body's center of gravity is brought forward, the toes remain planted while the heels are lifted up off the ground. While the toes do enter into this hypertended position before the body leaps upwardly, we will not bring this positioning of the toes into discussion since no muscles are attributed to this hyperextension. Rather, the weight of the individual forces the toes into a passive extension. Before the individual performs too much dorsiflexion and loses their balance, they will begin to transition into the next movement phase.

Take Off Phase

This second phase of hopping is characterized by an extending of the legs (knee and hip joint extension, along with ankle plantar flexion) and a flexing of the toes. Additionally, from the upper body we see flexion of the neck to bring it back into the extended position the individual originally had while standing and slight elbow flexion at the peak of the hop.

Focusing on the lower body first during this phase, take note of how the several joints work together simultaneously to propel the individual into the air. In discussion from superiorly to inferiorly, the muscles of the hip that will contract to bring it into extension are the muscles that are antagonistic to hip flexion. These prime hip extensors comprise the gluteus maximus, biceps femoris (long head), semitendinosus, and semimembranosus. It is also important to note that as the individual is extending their hip, the spine is brought back from a hyperextended position into an extended one by the anterior muscles of the trunk. Recall that as the hips were flexing during the Starting phase, the torso remained erect even though the line of gravity now fell on the back of the individual. Naturally, the portion of the body that the line of gravity falls upon changes (off of the back muscles) as the hips are extended. The trunk is flexed from a hyperextended position into an extended one with the use of the anterior trunk muscles. As mentioned earlier when noting the muscles antagonistic to trunk extension, the trunk-flexing muscles include the rectus abdominis, the internal oblique, and external oblique. And as for the transverse abdominis, its role is abdominal support throughout the physical activity. As the hip extends, so does the knee joint. The muscles of the quadriceps group make knee extension possible; collectively, they are the rectus femoris, vastus lateralis, vastus medialis, and vastus intermedialis.

As we travel down the leg below the knee, the next joint we see involved is the ankle joint. The last we spoke about the ankle it was dorsiflexed to such a great degree that the entire body weight was resting on the toes of the foot with the heel elevated superiorly, causing the toes to passively perform hyperextension. Just before the individual can “face plant” from continual dorsiflexion, they extend their hip and knee joints and enter into a forceful plantar flexion to assist the rest of the lower body in resisting gravity’s effects on the individual. Additionally, the toes also assist with pushing the body off the ground by flexing back into their extended position; they will remain in this position until the body lands. Recall that during the Starting phase we mentioned that the gastrocnemius played a role in knee flexion; it is able to do so because it's origin is located above the knee joint and spans this joint to insert into the calcaneus bone of the heel. Additionally, this muscle is also responsible for plantar flexion of the ankle. Also assisting with plantar flexion are the muscles known as the soleus, which lies deep to the gastrocnemius, and the plantaris. Other muscles that assist this heel-lifting motion are the tibialis posterior, flexor hallicus longus, and flexor digitorum longus. In regards to the muscle contractions that result in toe flexion (from hyperextension into extension), there is the flexor hallucis longus (great toe) and the flexor digitorum longus (four lesser toes). Immediately after these muscles flex the toes into extension, the body will travel upwardly and forward through space. The toes will remain extended as the body travels through space until gravity brings the body back to Earth and the weight of the individual transitions to rest back onto the toes.

Before we conclude our discussion of the Take Off phase, we must discuss the muscles involved in causing motion in the upper body—flexion of the neck and slight flexion of the elbows. Neck flexion occurs during this phase in order that the vision field may remain forward throughout the physical activity. Neck flexion is attributed to the scalene muscles (anterior, middle, posterior), the longus colli and capitis muscles, and the rectus capitis anterior. During this phase of the hop, the body is being sent the opposite direction of the ground but will eventually be overcome by gravity. During the moment when the body ceases to elevate (the peak), minimal flexion of the elbows can be observed. This is a passive joint action because the momentum created from the jump is pushing the forearms upwardly while the rest of the body is being forced back down by gravity, and therefore, cannot be contributed to the musculoskeletal system.

Flight Phase

Now that the body is actually off the ground and traveling through the air, we have entered the Flight phase of hopping. During this phase, we see the least amount of movement (which is good in perspective to energy expenditure since much movement has already been required to get off the ground). The only movements that occur during the Flight phase are dorsiflexion of the ankle joints and extension of the knee joints. Also consider, though, that since the individual is in a vertical position "flying" through space, an isometric contraction must be taking place between the trunk extensors and flexors to keep the trunk upright in this neutral spinal alignment.

Remember that the ankles of the individual greatly contributed to making them air-born. In order to land in such a way that is beneficial to the knee joints, both ankles will need to dorsiflex to such an extent (very little) that the whole foot is be able to make contact with the ground as soon as landing occurs. Since dorsiflexion is not new to this discussion, the muscles involved to create this joint movement are listed above. In regards to the knee extension occurring during this phase, it is just before the individual lands that we see the knees fully extend. We've already discussed that knee extension is needed to lift the body off the ground; as the body takes flight, we see the muscles that cause the knees to extend will continue to contract until they pull the knee joint into its full range of motion, right before the body lands back on the ground.

Ending (Landing) Phase

We all know that what goes up, must come down. This phase of hopping is the final, and it is reached when the individual is no longer able to remain disconnected with the ground. As the feet make contact with the ground, the rest of the body spanning upwardly reacts to the compressive force of the hop by simultaneously flexing the hip, knees, and ankles. Additionally, the head will transition back into hyperextension so that vision is not limited to only what is below. And, alas, we are back into the squatting position that was originally assumed during the Starting phase of the hop! However, it is worthy to note that though we've now returned to our Starting phase, the sequence of hip flexion and knee flexion looks different now in comparison to when the individual was standing straight up because now there has now been produced a downward force being applied to the body (in the Starting phase, hip flexion initiated movement to the individual before any other joint, while now during landing we see all joints in action at the same time). From a biomechanical perspective, we can learn the importance of landing the way described above. By allowing the joints of the lower body to "give" upon the impact of ground reaction forces, the individual is able to manipulate the interval of time it takes for the Earth to cause a change in the individual's momentum. Doing so reduces the amount of force applied to the joints during the impact of landing, and thus, dismiss damage to the lower body joints.[4]

CONCLUSION

The physical activity of hopping is one that many among the younger population enjoy. It is a good activity to utilize to encourage healthy habits to children, and it is easy to do. However, to ensure the health of children, it is not enough to encourage them to actively participate in hopping or other physical activities, but to also teach them how to play in such a way that is most beneficial for their bodies. In the example of hopping, it is a common error in execution to see children (and even individuals of other age groups) land with a stiff lower body. The best procedure to correct this error is to allow the center of mass to be brought down towards the ground as one lands from a hop. It is absolutely crucial for children to understand the importance of absorbing shock as they land; though a disregard for proper landing maneuver appears to result in minimal damage (if any at all), such continual forces over the span of one's life will likely lead to chronic injury, in particularly to the knees. Another common error seen in hopping, predominantly by children, is the lack of joint action of the ankles and toes. These are the individuals who execute the hop with flat feet. In order to perform the most successful hop possible, one should not only extend the hip and knees but also plantar flex the ankles and flex the toes. Obviously, though, if an individual has any weak or injured muscles associated with hip and knee extension, or plantar flexion, hopping will not be an easy task. Hopping will also be more difficult to do with the arms extended and/or abducted away from the center of mass, the core of the individual.

Hopping can still be made difficult, however, even for those with strong or uninjured activity-associated muscles. Though an activity more common in the younger population, hopping can be altered to be used as a plyometric exercise for people of an older population. This type of exercise is advanced and should not be attempted by the untrained—those who are not accustomed to less intense lower body exercises. Also, a person's balance should be brought into account when considering engaging in a plyometric exercise routine. Those who possess balance deficiencies, such as the elderly, are more susceptible to injury while engaging in plyometric exercises and should consider constructing proficiency in less challenging lower body exercises first.

Hopping is a great way to get children active, and it can even be intensified so that older populations may also reap benefits from it. Whatever the age of the individual interested in hopping, it is important that they be educated on how to perform the physical activity in the most biomechanically efficient way. By being active through physical activities such as hopping and many others, individuals are able to build greater lower body muscle strength (which is helpful since the lower body contributes to the body's locomotion) and lead healthier, happier lifestyles.

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