

Ground-Reaction Forces During Form Skipping and Running

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Context: Form skipping has been used to help injured athletes progress to running. Because little research has been done on form-skipping mechanics, its justification as a progression to running exercises is unclear. **Objective:** To compare ground-reaction forces (GRF) during form skipping and running in healthy subjects at clinically relevant speeds, 1.75 m/s and 3.83 m/s, respectively. **Design:** Dependent *t* tests ($\alpha = .05$). **Setting:** Sports-injury research center. **Participants:** 9 male college athletes (age 20 ± 1.33 years, mass 848.4 ± 43.24 N, height 1.80 ± 0.07 m). **Main Outcome Measures:** Average (Fz_{avg}) and maximum (Fz_{max}) vertical GRF and (Fy) braking impulse were compared. **Results:** Fz_{avg} and Fz_{max} were greater during running than during form skipping ($P < .05$). Braking impulses were not different ($P > .05$). **Conclusions:** It appears that Fz , but not the Fy , GRF might explain why form skipping might be an appropriate progression to running. **Key Words:** running, lower extremity rehabilitation, functional rehabilitation

Form skipping, or A-drills, is an exercise used in speed-development training.¹⁻⁵ Form skipping, like childhood skipping, is a step and a hop on 1 leg followed by a step and a hop on the opposite leg. The childhood skip typically emerges developmentally after running, galloping, and hopping and is thought to be adopted for playful reasons in children and increased stability in adults.⁶⁻⁸ The form skip employs the same locomotor pattern but emphasizes posture, arm action, foot position, and a high knee march with a skip (see Figure 1).

Some clinicians have employed the form skip in rehabilitation and reconditioning programs for athletes recovering from lower extremity injury. Traditionally it has been implemented in the later stages of rehabilitation near return to play, after the athlete has regained the ability to run, but we have successfully used the activity for over 7 years, not as a drill after running but as a progression to running. Athletes demonstrating compensatory action and lack of symmetrical gait during running at particular stages of rehabilitation have been able to perform form skipping with excellent tolerance.

Running is an important skill for athletes recovering from lower extremity injuries to attain. Athletic trainers should provide progression activities that not only are safe but also simulate movements an athlete will perform while competing.

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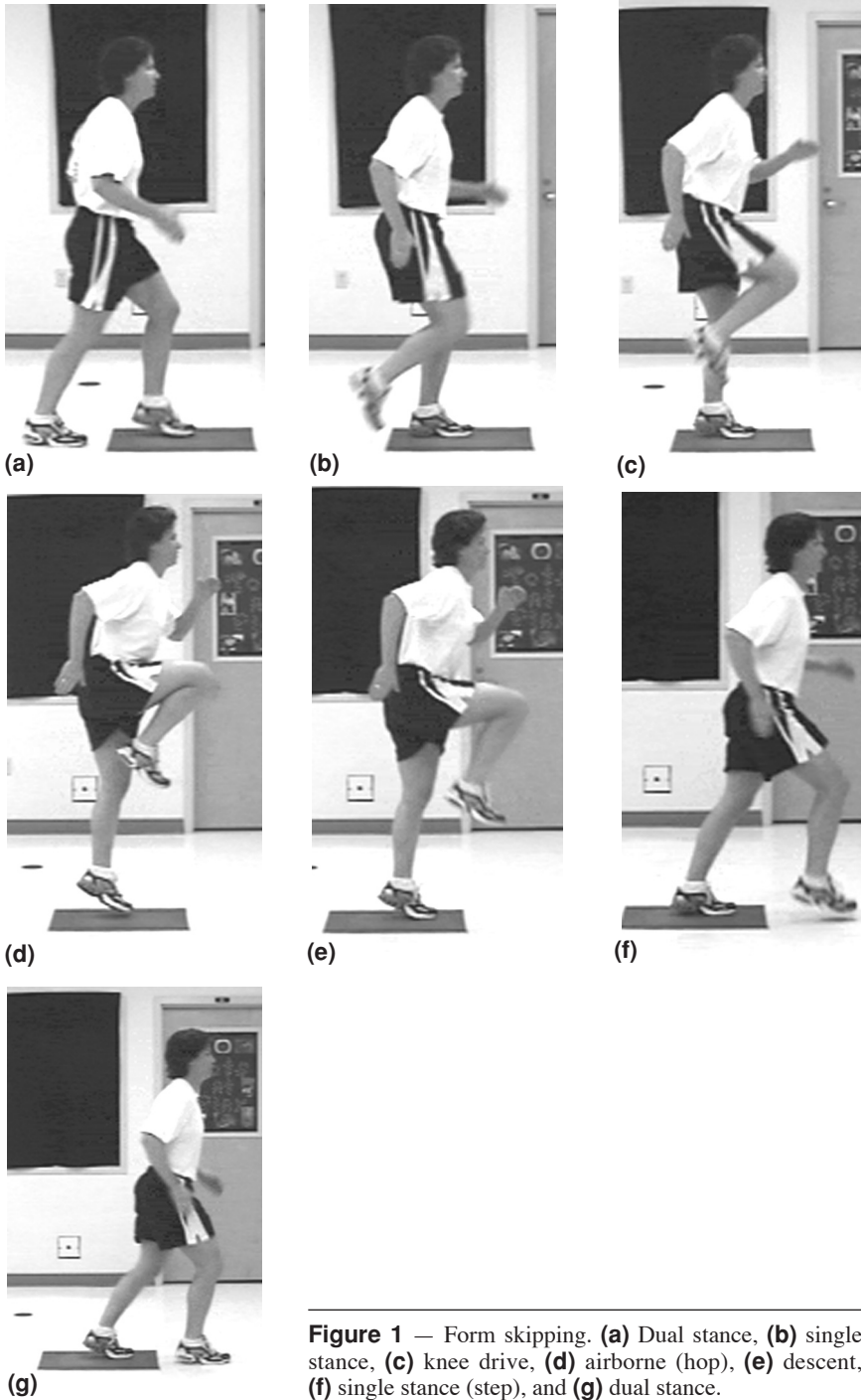


Figure 1 — Form skipping. (a) Dual stance, (b) single stance, (c) knee drive, (d) airborne (hop), (e) descent, (f) single stance (step), and (g) dual stance.

Based on our experience, form skipping is one such activity. Presently, little research has been done on the mechanics of form skipping, so there is no empirical evidence supporting (or refuting) its use as a means to progress to running exercises.

Ground-reaction forces (GRF) provide information regarding the forces exerted on the foot during locomotion, as well as acceleration of the body's center of gravity during the support phase of locomotion.⁹⁻¹³ Because there is presently no information available regarding the mechanics of form skipping, the purpose of this study was to describe the GRF during form skipping and running.

Methods

Thirteen college-age male varsity athletes volunteered to participate in the study and gave written informed consent. The study was approved by the university's institutional review board. Subjects reporting a history of lower extremity injury in which treatment was received for longer than 7 days or of lower extremity ligament surgery or who were currently suffering from a musculoskeletal injury were not included in the study.

The setting for this study was a university sports-injury research center. A force platform (Model 9281B, Kistler Instrument Co, Amherst, NY) was mounted in the middle of a 13-m runway. The force platform was connected with an 8-channel charge amplifier (Model 9856B) interfaced with a CIO-DA516-F analog-digital (A/D) board. GRF data were collected at a sampling rate of 1000 Hz. Locomotion speed was quantified using a Brower Timing Light Speedtrap 2 System (Brower Timing Systems, Draper, Utah) with sensors placed 2 m in front of and behind the force platform.

Subjects completed a 5-minute warm-up on a Monark GIH Cycle Ergometer (Monark, Stockholm, Sweden) set at 360 kg/min while viewing an instructional video describing the components and proper mechanics of the form skip. After the warm-up and video, each subject completed a training session on the proper mechanics of the form skip. Following are the instructions provided them^{1-5,14}:

- In this study you will be taught how to form skip. This skill is also called form marching or A-drills. It will be taught in a progression from high knee marching to high knee marching with a skip.
- Begin by performing a high knee lift with the left leg.
- The right knee should be flexed so the right foot is level with the left knee, both horizontally and vertically. The foot should be cocked, or dorsiflexed.
- The other leg should be fully extended, rising on the ball of the foot.
- Try this now.
- Your foot should contact the ground in the same cocked position landing on the midfoot.
- Elbows should be flexed at about 90°.
- The arm should be thought of as a pendulum, with the shoulder as the pivot point.

- The arms should be moved through the range of motion in a snapping or punching action with the hands moving from shoulder level to the hip.
- The torso should be angled slightly forward to mimic a form seen with running.
- Try now combining the upper body with the form march.
- Once mastered on 1 leg, the other leg should be performed, progressing to continuous, alternating legs.
- Practice this now until you feel comfortable performing this for roughly 10 ft.
- Next you will add a small hop or skip to the drill.
- While skipping, keep the foot close to the ground.
- Try this now. Remember everything is the same as the form march, but this has a skip added to it.
- Practice this skill down the runway until you feel comfortable.

The training began with form marching, progressing to form skipping. Form skipping was performed along the runway at 1.75 m/s. This speed was selected based on speeds typically observed clinically when form skipping has been used in rehabilitation. Subjects practiced the form skip until they were comfortable performing the skill and their performance met the experimenter's satisfaction. Experimenter's satisfaction was defined as the ability of the subject to perform error-free form skipping at the selected speed and contacting the force plate during the proper phase of the gait (see Figure 1). Subjects were then allowed to practice running along the runway until they were comfortable running at a speed of 3.83 m/s and contacting the force plate with the same foot. Again, this speed was selected based on clinical observation of athletes returning to running after lower extremity injury.

After this orientation and instruction session, subjects completed trials while running and form skipping, with order of conditions counterbalanced. Each subject was required to complete 10 successful trials of both form skipping and running. A successful trial was one in which the subject contacted the force platform in a normal stride pattern at the designated pace. The maximum number of attempts the subjects was allowed to complete to obtain 10 successful trials was 30. Using these criteria, 4 subjects were excluded from the data analysis, leaving 9 subjects in the final analysis (age 20 ± 1.33 years, mass 848.4 ± 43.24 N, height 1.80 ± 0.07 m).

Treatment of Data

Support-phase GRF data were extracted by identifying initial ground contact and takeoff times based on a 50-N force criterion. Average (Fz_{avg}) and maximum (Fz_{max}) vertical GRF were recorded and normalized to body weight. For Fz_{max} , only the midstance maximum was used, not an impact peak if there was one. Horizontal (Fy) GRF was analyzed by calculating braking impulse as the area under the force–time curve in the anteroposterior direction during the phase in which the anteroposterior GRF component acted in a direction opposite to the direction of locomotion.

Because the laboratory had only 1 force plate, only 1 phase of the form-skip gait cycle could be examined. For the purpose of this study, the first phase of the gait cycle, descent from the trailing leg and propulsion into the hop, was evaluated (see Figure 1).

Of the 10 running-condition trials, the 3 trials that had braking and propulsion impulses closest to a ratio of 1 were selected for analysis. For form skipping, because skipping is an asymmetrical gait, it was impossible to use the braking and propulsion impulse ratio; therefore the 3 trials closest to the selected speed of 1.75 m/s were chosen for evaluation. The dependent variables (Fz_{avg} , Fz_{max} , and Fy braking impulse) were compared between locomotion conditions using dependent t tests ($\alpha = .05$).

Results

Fz_{avg} and Fz_{max} were different between form skipping and running ($P < .05$). The Fy braking impulse was not significantly different between form skipping and running ($P > .05$). See Figures 2 and 3 for typical Fz and Fy GRF curves for both form skipping and running.

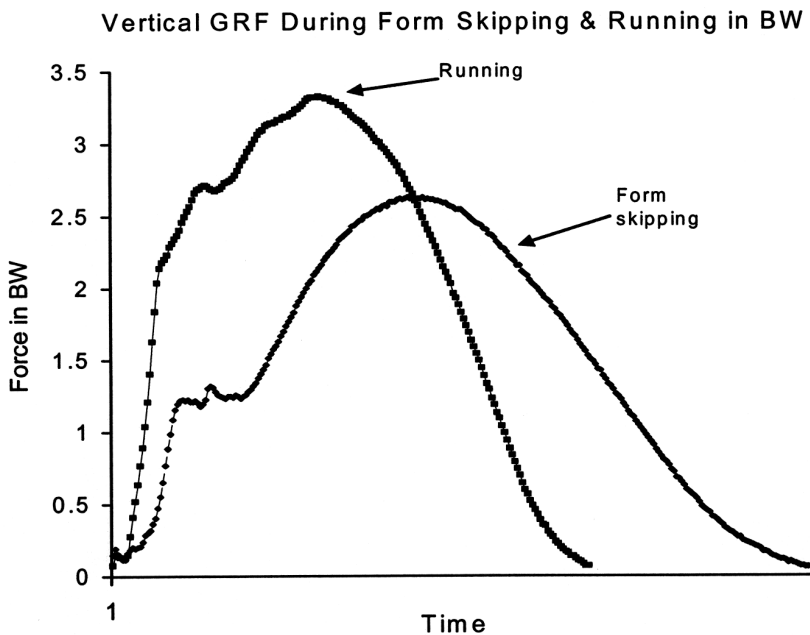


Figure 2 — Example vertical ground-reaction-force curve during form skipping and running.

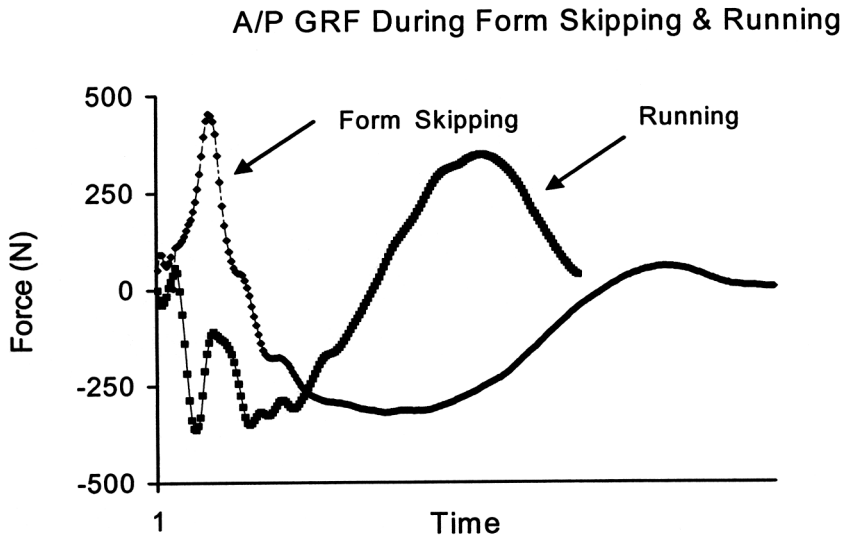


Figure 3 — Example anterior/posterior ground-reaction-force curve during form skipping and running.

Comments

Form skipping has been used in the rehabilitation of athletes recovering from lower extremity injury. Traditionally it has been included near return to play. We, however, have used form skipping in a novel way — as a progression to running after lower extremity injury. The purpose of this study was to describe the GRF during form skipping and compare those forces to running in order to provide some empirical evidence supporting or refuting the hypothesis that form skipping can serve as a progression to running. We observed that the F_z GRF during form skipping was approximately 20% less in magnitude than that during running, but braking impulse during form skipping was not different than during running.

It is known that as running speed increases, the F_z GRF will also increase.^{6,8,9} Because the form skipping was done at a slower speed than the running trials, it might be that the differences in GRF are explained solely by differences in locomotion speeds. We selected the locomotion speeds in order to reflect the clinical use of form skipping and have observed that vertical GRFs are lower during form skipping than during running at these clinically relevant speeds. We did not compare the GRF during running and skipping at similar speeds because form skipping is not appropriately done at running speeds and it is difficult to truly run at speeds appropriate for form skipping.

Based on this introductory investigation we discovered several interesting characteristics about form skipping. First, form skipping, like walking, has a dual support phase, but, like running, it also has a flight phase. That is, like walking there

is a portion of the gait cycle when both feet are in contact with the ground, but like running there is also a portion of the cycle when both feet are off the ground. The flight phase is identified during the hop portion of the form skip and does not occur during the transference of ground contact from 1 limb to the other. Does this mean that skipping is a practical progression to running because it exhibits characteristics of both walking and running? Possibly, but it is known that developmentally, children do not skip until after they learn to run and abandon the gait after they mature.³⁻⁵ Nonetheless, 7 years of clinical application has revealed that athletes recovering from lower extremity injury are able to form skip before running.

Second, Minetti noted in his study on childhood skipping that the dual support phase during skipping increases the stability of the combined push.⁸ Because both forms of skips use the same step-and-a-hop pattern perhaps this increased stability might enable athletes to decrease the need to exert force on the unhealthy leg during the impact phase. Initially during rehabilitation, form-skipping speed is primarily patient directed. In other words, the clinician instructs patients to skip at speeds at which they are comfortable performing while giving feedback regarding technique. The contribution of force production and absorption during dual support can be self-regulated without loss of the rhythm or with significant observable compensation. Theoretically, the assistance provided by the uninjured limb during dual support might aid the healing limb while still allowing the athlete to demonstrate tolerance to this locomotor skill. As the limb becomes stronger increased forces are tolerated, and speed can be increased accordingly. To confirm this, further study needs to be undertaken using more than 1 force platform and examining athletes recovering from lower extremity injury.

In conclusion, progression to running is an important step for athletes to take when recovering from lower extremity injury. Clinically, we have been using a traditional late-term rehabilitation exercise, the form skip, in an alternative way. By introducing form skipping before running we have observed successful results with little understanding as to why. Therefore, we measured GRF and discovered that F_z GRFs are lower during form skipping than during running at the speeds examined, which perhaps helps explain why form skipping is a progression to running. Much work still needs to be done to ascertain why form skipping is a successful progression to running, such as GRF of both limbs, joint-reaction forces of the lower extremity, and GRF of injured athletes as they progress from walking to form skipping to running.

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