The Physics and Forces of Partnered Lifts in Dance

Kenneth Laws, Ph.D.

Dance training is the process of learning how to manipulate one's body both internally and in interactions with the "outside world" to express aesthetic images through human body movement. When a dancer interacts with the outside world (everything outside of the dancer's own body) only through gravity and contact with the floor, the complexity of such interactions is limited. The forces are known, mostly controllable, and not subject to uncertainties of externally determined timing. But when a partner is involved, the forces of interaction with the "outside world" are infinitely more complex and significantly less controllable by the individual. In fact, part of the beauty and captivating nature of a *pas de deux* results from the challenge of coordinating two different minds and bodies. That coordination between partners must be learned and eventually sensed.

Dancers often push themselves to their physical limits to maximize the range and variety of movements they use to express themselves. Exceeding those physical limits of the body is more probable in partnering than in dancing solo because of the loss of total individual control. Thus dancers working with partners are particularly susceptible to injury. In lifts, for instance, the lifted woman must depend on her partner for support at the right places on her body and for control of the descent to the floor. Her partner must depend on her to control the configuration of her body and the timing of her jump in order to achieve the most effective use of the strength of both of them in performing a smooth lift. If the coordination is not there, the unexpected stresses can cause injury in either partner.

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What kinds of stresses on the body can lead to injury? When a man is supporting a woman, her weight is not totally supported in the normal way—at the feet. For an overhead lift, the man may be supporting her weight at the small of her back; for a straight vertical lift, he may provide support under her rib cage; in a horizontal position, called a "fish," he should support her at the thigh and the ribs. In the last case, if the man's technique is faulty, he may be supporting her at an uncomfortable location between the ribs and the hip bones, leading to pressure-related problems with internal organs.

From the man's perspective, controlling a non-rigid weight equal to perhaps three-fourths of his own weight can be tricky and demanding. For high lifts, his back takes substantial compressive stress, particularly in the lumbar region when its curvature is exaggerated. Since the woman's weight is often borne by the man's hands, the position of the hands is important in avoiding unnecessary stress. If his arms are not vertical, there is substantial torque in the shoulders with possible muscle or tendon injury.

Physicians have the knowledge of the body and training to determine what happened in case of an injury to a dancer. But it is often difficult for a physician to determine *why* an injury occurred, or what activity led to the injury. For that purpose there needs to be interaction between those who know the body and those who are familiar with the activity. Ideally the physician who knows the body is also familiar with the activity of dance through participation or close observation. In any case, dancers, dance teachers, choreographers, and others must communicate intelligently with the medical community. At that point there are difficult barriers of language, in that performing artists often use terms and images that must be translated into the objective language with which health professionals deal. And medical people must try to understand the images that the artist uses.

One important link between those who deal with the body and those who deal with the activity of dance involves the physical principles that translate

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movements into forces and stresses. In a particular type of lift, for instance, a smooth appearance may be translated into a functional dependence of vertical acceleration on time, which translates into the vertical force exerted on the woman by her partner. Knowing the timing of that vertical force allows one to evaluate where the stresses can be sufficient to be potentially injurious. To the dancer or dance teacher, that knowledge may lead to a basis for a change in the technique applied to the movement.

In recent years increasing attention has been given to medical problems of dancers. This journal, along with *Kinesiology for Dance* and others, is reporting recent work in the area. *Clinics in Sports Medicine* contains a series of articles specifically on dance injuries.[1] *Dance Kinesiology* by Sally Fitt has just been published by Schirmer Books. There are also publications dealing with the technique of partnering. One of the most detailed is N Serebrennikov's textbook, *Pas de Deux*, published in Russia in 1969, which was translated and edited for a series that began in *Dance Magazine* in January 1978. Specific references to the physical principles or injuries in partnering are rare. They include a series of short articles on lifting technique by Tony Lycholat which appeared in *Dancing Times* in 1982.[2] Lyle Micheli, a Boston-area physician active in dance medicine, wrote an article on back injuries in dancers that specifically refers to problems arising in partnered lifts.[3] In *The Physics of Dance*,[4] the physical principles that apply to many dance movements, including partnered lifts, are described.

Let us look at the process of the coordinated jump and lift. How much of the total energy required is contributed by the woman and how much by the man? How does the lifting force exerted by the man vary with time during the lift? Where is that force greatest and where is it least? What are the implications of the timing of these forces on the potential for injury? How are these processes different for the straight lift (Fig. 1) and the overhead lift (Fig. 2)? How are the positions of the hands, which are responsible for transmitting the vertical force from the man to the woman, related to the magnitude of the force?

A Study of a Straight Lift

In order to answer these and related questions, a study was undertaken in which a series of straight lifts was videotaped and analyzed. The video camera was positioned so that two images of the lift were recorded: one close up, in which position marks on the woman's body were clearly visible throughout their vertical range of position, and a mirror image side view from farther away, allowing body configurations in the sagittal plane to be seen, and the moment when the woman's feet left the floor to be determined (Fig. 3). A frame-by-frame analysis of the recorded images allows the woman's vertical position to be measured as a function of time. If her body configuration is constant once she leaves the floor, these vertical positions are directly related to the vertical positions of her center of gravity. A kinematic analysis of position allows vertical velocity and vertical acceleration to be determined. The amount by which the vertical acceleration differs from the acceleration due to gravity is a direct measure of the vertical force exerted by the partner once the woman has lost contact with the floor. That is, gravity and the partner are the only sources of vertical force acting on her after she has left the floor, and the total of these two forces produces the measurable acceleration.

In order to test the validity of the experimental setup, the first measurements were done with the woman jumping alone so that gravity was the only acting force. The vertical acceleration should be measured to be "g", the acceleration due to gravity, where $g = -9.8 \text{ m/S}^2$. (The negative sign indicates that the acceleration due to gravity is downward; upward is conventionally defined as the positive direction for acceleration.) Measurements from the video tape showed an acceleration of -9.6 m/S^2, indicating an accuracy of the order of 2%, quite acceptable for these purposes.

FIGURE 1. Lisa de Ribère, formerly of New York City Ballet and American Ballet Theatre, and Sean Lavery, of the New York City Ballet, perform a "straight" or temporary lift, in which Lisa's center of gravity is not directly over Sean's area of support at the floor. (Photo by Martha Swope from *The Physics of Dance.*[4])

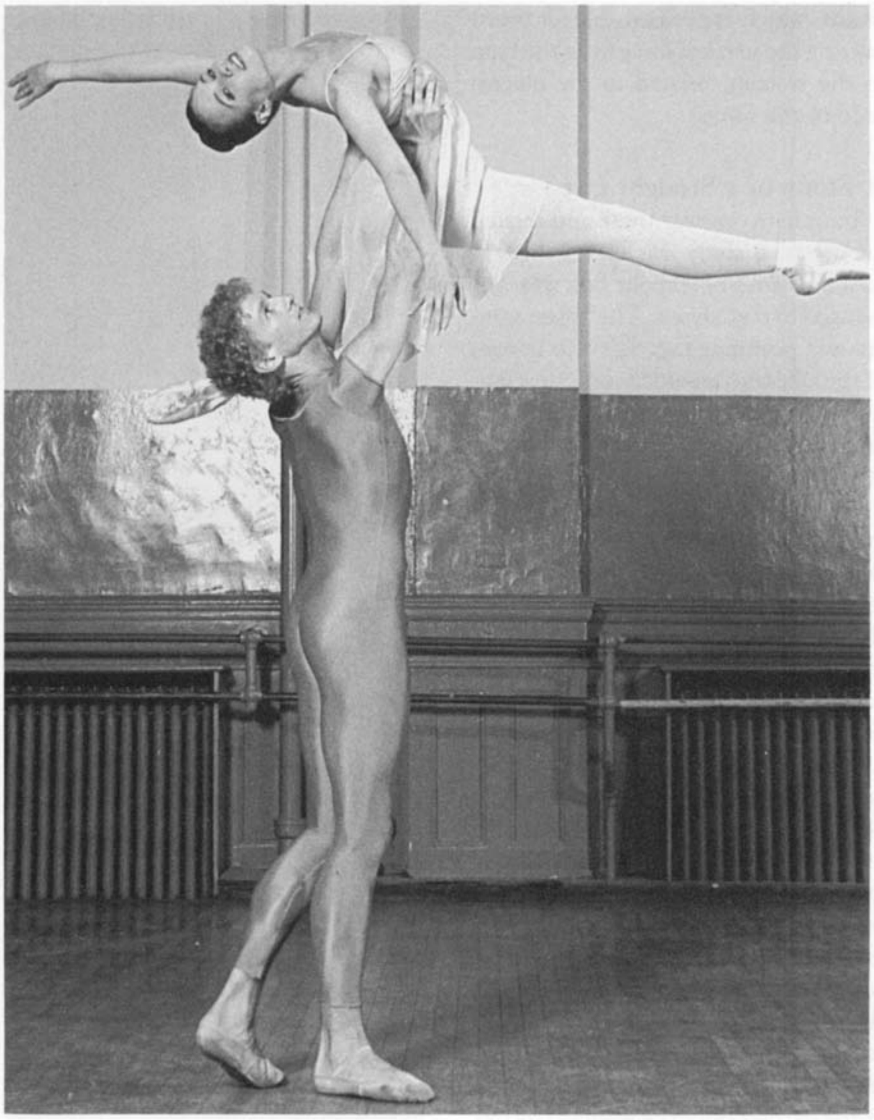

FIGURE 2. The same dancers perform a stable overhead lift, in which Sean's vertical supporting force is equal to Lisa's weight. (Photo by Martha Swope from *The Physics of Dance.*[4])

Several lifts were performed, with some variations in the man's position (distance behind the woman), stance, and presence of forward thrust at the peak. When the lift was successful, there were no differences in the measured force that could be associated with variations in technique. Therefore, a lift that produced data that was reasonably smooth and complete was chosen for analysis.

Figure 4 shows the velocity as a function of time during the lift. This is calculated from the differences in vertical position, with each velocity associated with a time midway between the times of the measured positions. A fifth order polynomial function that best fit the velocity-time data was determined, then differentiated with respect to time. The resulting fourth order polynomial represents the woman's vertical acceleration. The difference between those accelerations and "g" is then plotted in Figure 5, in units of lifted weight. (This means that the vertical force exerted by the man on the woman is equal to her weight when the value of the vertical coordinate is 1.0.)

Analysis

This analysis can provide valuable insights into the lifting process, insights that have implications for the potential for injury or provide a more general understanding. For instance, how much of the total required energy for the lift is provided by each partner? Assuming the woman's jump is the same whether or not a partner is lifting her, the height to which she jumps alone is a measure of the net gain in potential energy resulting from her jump. The height attained in a supported lift is a measure of the potential energy gained by a combination of her jump and the lifting partner's efforts. A comparison of those heights shows that the woman contributes about one-fourth of the total energy, and the man three-fourths.

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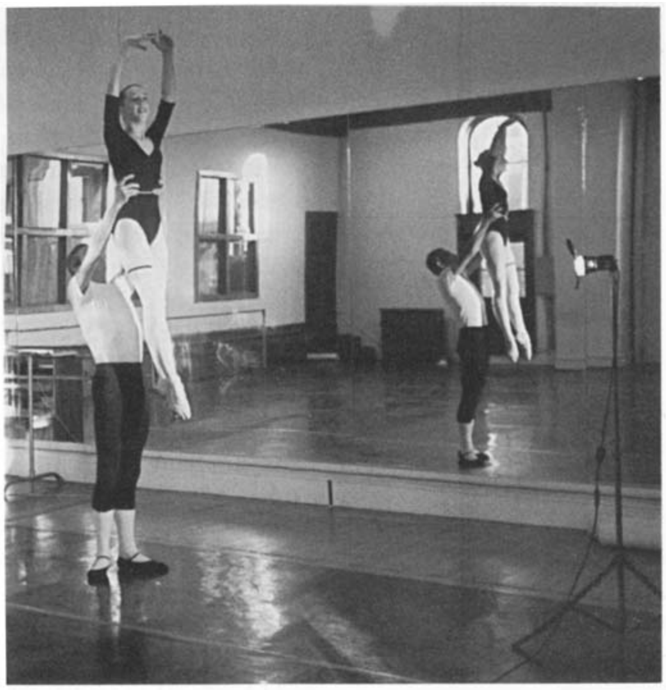

FIGURE 3. The author and Shane Utsch perform the straight lift analyzed in this article. (Photo by John Steigleman.)

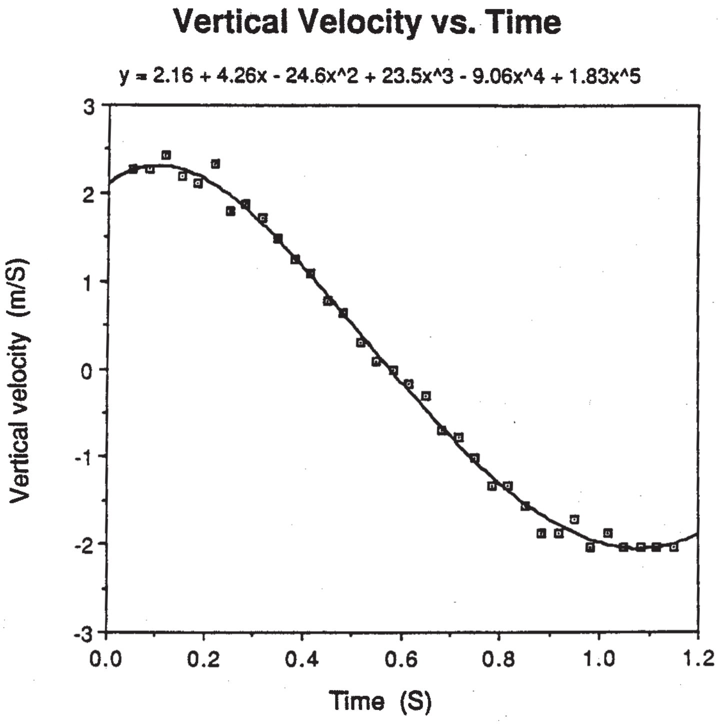

FIGURE 4. This graph shows the vertical velocity of the lifted dancer as a function of time during the straight lift. Time equals zero when Shane's feet leave the floor.

Figure 5 shows that the vertical lifting force exerted by the man is large at the beginning of the lift, where it is somewhat greater than the woman's weight. Although the man is exerting force from the time the woman begins her jump, the graph begins at the time when her feet are no longer in contact with the floor, so that the only vertical force overcoming gravity is applied by her partner. Approaching the peak of the lift, the supporting vertical force decreases to about 30% of her weight. During the last part of the lift, the supporting force that slows her descent increases again to a value somewhat greater than her weight.

Does this observed variation of force with time make sense? Clearly if the man exerts a constant force equal to the woman's weight, she would rise with constant speed until she left his hands, in a vertical "throw." Clearly the force must decrease with height for her to come to rest at the peak. But the greater the force early in the lift, the greater is the achievable height. In fact, ideally, the force would be great enough early in the lift to accelerate her to the speed necessary for her to coast upward to a stop just as she reaches the height where her partner's arms are fully extended. If the timing of the lift is to be extended, then the force would have to be smaller early in the lift so that she does not accelerate upward as quickly. But the force will remain larger approaching the peak so that she still attains the full height. If the force is greater near the peak, she will accelerate downward more slowly after reaching the peak.

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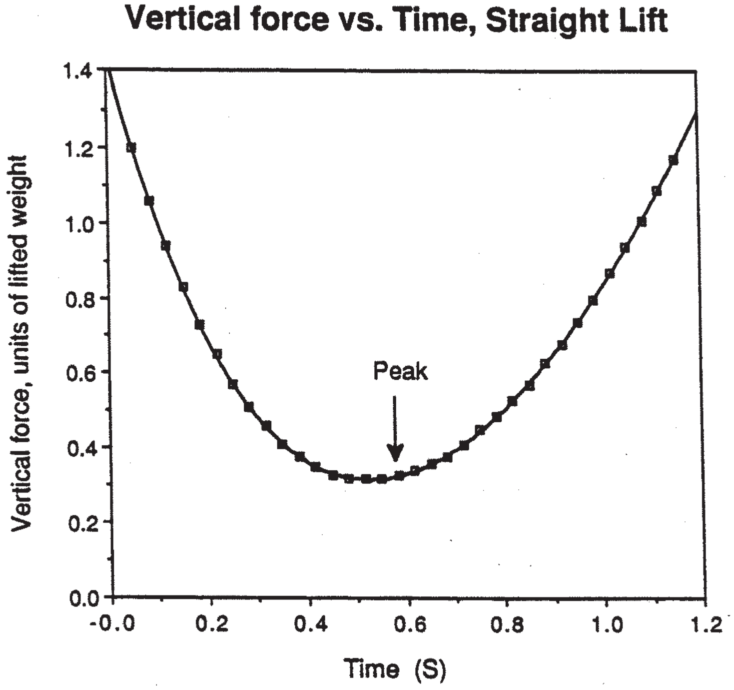

FIGURE 5. The vertical force exerted by the man for a straight lift is plotted as a function of time. This force is determined from the acceleration, which was obtained by taking the time derivative of the fifth order polynomial curve fit to the velocity graph. A value of 1.0 on the vertical scale represents a vertical supporting force equal to the weight of the lifted dancer.

landing sufficiently gentle to avoid injury. In fact, if the supporting force varies with time symmetrically around the peak of the lift, her vertical velocity upon landing will be the same as if she jumped without support. If the man's supporting force is less on the descent, she will land with correspondingly greater vertical velocity and stress on the body than from her own unsupported jump. And that creates a situation that can lead to injury.

One might expect that the vertical supporting force would be greater at the peak of the lift than that found in this experiment, since the peak is where the man's arms are straight and therefore strongest. However, the position of his hands at her waist makes it difficult to exert that vertical supporting force. He depends somewhat on the base of her rib cage to receive the vertical force, but must also depend largely on friction between his hands and her body. That frictional force is proportional to the perpendicular force holding his hands against her body. That force is turn depends on a torque exerted at his shoulder, with a very long, and therefore ineffective, moment arm for that torque being translated into a force holding his hands against her body. There is thus an inherent limitation in the effectiveness of a vertical supporting force at the peak of the lift. The force can be greater near the beginning and end of the lift for two reasons. First, when his hands are in front of his body, the pectoral muscles used to push the hands toward each other are quite strong. When the arms are overhead, however, the deltoids are used in a range where they are not as effective. Second, during the early and late phases of the lift, the stronger legs rather than the arms are doing much of the lifting.

The Overhead Lift

How, then, is the second kind of lift, the overhead lift, carried out successfully? If the woman is supported at constant height for some time at the peak of the lift, the vertical force exerted by her partner must equal her weight, which is significantly greater than the observed force at that point in the straight lift. The beginning of the lift can be very similar, but at the peak the man must shift the position of his hands in such a way that the support is from the heels of his hands to the woman's back. How and where in the lift is that shift in hand position carried out? The vertical force must be large enough early in the lift that she can coast to the peak with his supporting force decreasing to essentially zero. At that point, when he is exerting no vertical force, he is free to shift his hands to the desired position at his partner's back. Of course, she must be sufficiently arched at that time so that he has a horizontal surface to support, since friction can no longer play a significant role in providing for a vertical force. Now when the woman is at the peak of the lift, her partner exerts a force equal to her weight in order to hold her in that position for the time required by the choreography. The descent is then controlled as before, but, with his hands at her back rather than waist, the vertical supporting force becomes less effective as she approaches a vertical orientation. Care must be taken to prevent a hard landing from this type of lift.

Some of the analysis from the straight lift studied can be extrapolated to an overhead lift, providing similar insights into the techniques used and possible injury potential. Suppose the woman's vertical velocity at the time of her departure from the floor is the same as that observed for the straight lift. Suppose also that the velocity decreases smoothly to zero when her center of gravity has reached the same maximum height. But in this case assume that the lifting force exerted by her partner decreases smoothly to zero at the peak so that he can shift his hand position, then quickly becomes equal to the woman's weight to hold her at a constant height. The graph of lifting force as a function of time in Figure 6 represents an example of the way the force varies under the constraints applying to this overhead lift. A comparison of this graph with Figure 5 shows that the force is indeed greater near the beginning, and does decrease to zero just before it suddenly rises to a value equal to the woman's weight

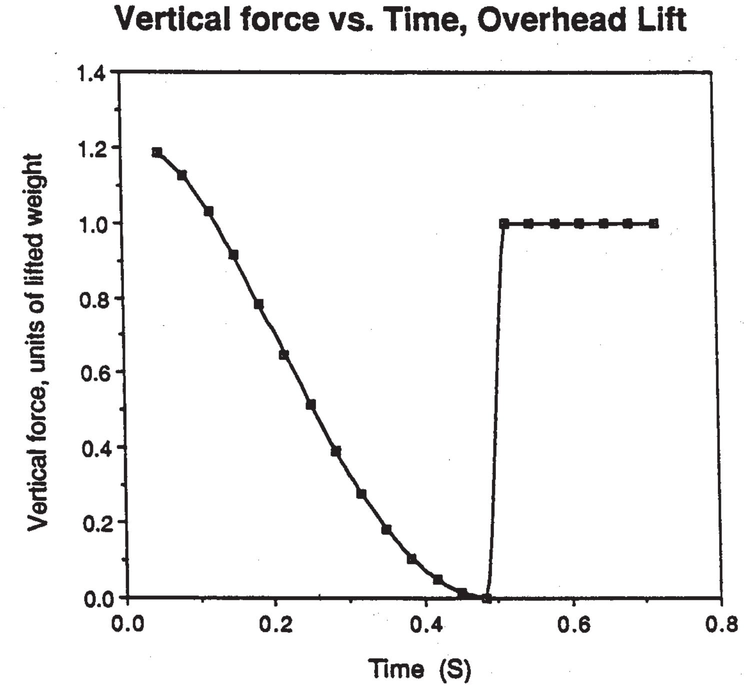

FIGURE 6. The lifting force exerted by the man for an overhead lift is plotted as a function of time. This force is determined from imaginary velocity "data" chosen to be consistent with the constraints inherent in this type of lift.

when she is supported at constant height.

There are some dangers in this type of overhead lift. A man with insufficient strength may be able to perform a straight lift (the first type described), in which the vertical force is great enough to raise the woman to the full peak, but not great enough to let the supporting force go to zero at or near the peak. He would then not be able to shift his hands to the required position on her back to accomplish the overhead lift. When she is in the arched position overhead, his hands would still be at her waist, and her full weight would be supported on his thumbs. This is a common problem in partnering, and can lead to strains or sprains in the thumb area of the hand.

Another problem can arise. Suppose the man's back becomes arched with a lordotic curvature near the peak of the lift (see Fig. 3), another common problem in lifting technique. If the vertical supporting force exerted on the woman is large at that point, the stress on the lumbar spine can be injurious. In a straight lift, the force may not be that great, and the injury potential is lessened. In fact, a forward thrust on the woman at that time can help her to maintain a vertical configuration with her legs and feet free of conflict with his body, and can also allow him to achieve straight arms at the peak, which otherwise might be difficult. But for an overhead lift, in which the force at the peak of the lift must be equal to the weight of the lifted partner, such a lordotic curvature of the lumbar spine can be a serious problem and should be corrected.

The specifics of this analysis, and particularly the quantitative results obtained from the experiment on the straight lift, clearly apply only to the particular partnership studied. The variation in vertical force exerted by a stronger partner might be expected to show an even greater variation with time, from a greater force at the beginning of the lift to a force closer to zero approaching the peak, then to a greater force slowing the descent and lengthening the duration of the entire movement.

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The general principles resulting from this study should apply to all lifting situations. Clearly the stable overhead lift in which the woman remains stationary aloft for some length of time requires a supporting force equal to her weight, while straight (temporary) lifts do not require as much supporting force. The potential for injury therefore will be greater for the overhead lift. Stress on the man's thumbs, wrists, and lumbar spine can be identified and alleviated with appropriate technique. The body configurations and timing of supporting forces can be adjusted to make the lift as smooth as possible with minimal risk of injury.

ACKNOWLEDGMENTS

I wish to thank Shane Utsch, a very talented dancer who was sufficiently strong, tall, and light to be lifted by the author for the studies reported here. I also acknowledge the help of Saundra Hampson, a Dickinson College student and dancer, who contributed help and ideas in the course of this study.

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