CENTER OF PRESSURE MOVEMENTS DURING WEIGHTLIFTING

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Although numerous studies of Olympic style weightlifting have been performed using a force plate for data collection, most have concentrated on the parameter of vertical force application (e.g. Enoka, 1979 and Payne, 1968). A few papers have shown extensive anterior-posterior center of pressure (CP) movement relative to foot support in data presented, but this topic was not discussed (Breniere, 1981 and Ueya, 1977). Only one report has analyzed CP movement during weightlifting (Garhammer, 1976). In the discussion of that study it was pointed out that CP movement showed some relationship to horizontal movement components of the barbell's trajectory. Balance on the feet and horizontal barbell movement are key components of proper lifting technique. Thus, an understanding of these parameters and their relationship would be very valuable to coaches for teaching technique. The purpose of this study was to obtain objective data on CP movements during execution of the classical lifts, and to determine if they are related to horizontal barbell movements.

METHODS

Six elite weightlifters ranging in body mass from 67.5 kg to over 110 kg served as subjects (Table 1). All had previously represented the United States in international competition, and all were potential members of upcoming international teams. Each executed three snatches or snatch pulls and two or three cleans or clean pulls on a Kistler force plate (type 9281B11) secured to the concrete floor and surrounded by a typical wooden training platform. During each lifting movement a Selcom Selspot system was used to monitor bar trajectory. A small light emitting diode was taped to one end of the bar and its emission was followed by an infrared sensitive camera whose optical axis was fixed parallel to the bar. The camera was placed five meters to the side of the training platform, with its height equal to approximately half the typical vertical movement range of the barbell. Analog signals representing horizontal and vertical bar coordinates were transmitted to an analog-digital converter, along with the analog signal representing anterior-posterior CP movement on the force plate. The three resulting sets of digital data were input to an Apple II computer.

TABLE 1: CENTER OF PRESSURE POSITION AND MOVEMENT COMPARED TO BAR MOVEMENT

SUBJECT	TRIAL	LIFT	WT(Kg)	%MAX	A	B	C	D	E	F	G
D.A.	1	SN	80	67	7.5	11.3	0.0	3.8	4.4	11.3	8.9
67.5Kg	2	SN	80	67	7.0	16.3	1.0	9.3	6.8	15.3	8.2
	3	SN	80	67	7.0	15.3	0.4	8.3	6.4	14.9	9.6
27.5cm	4	CP	120	75	7.5	14.5	3.3	7.0	---	11.2	---
shoe	5	CP	120	75	7.6	10.6	3.0	3.0	---	7.6	---
	6	CP	120	75	7.0	12.7	3.4	5.7	---	9.3	---
R.S	1	SN	110	67	8.6	11.4	-0.0	2.8	7.0	11.4	16.0
100Kg	2	SN	110	67	11.5	10.5	-0.0	-1.0	5.2	10.5	13.5
	3	SN	110	67	6.8	10.4	-0.0	3.6	7.9	10.4	14.1
30.4cm	4	CP	160	78	13.7	15.1	10.8	1.4	---	4.3	---
shoe	5	CP	160	78	13.6	15.2	11.0	1.6	---	4.2	---
	6	CP	160	78	13.1	13.6	8.7	0.5	---	4.9	---
K.C.	1	SN	127	80	12.4	20.0	4.5	7.6	10.2	15.5	7.9
100Kg	2	SN	137	86	11.8	19.5	3.2	7.7	10.7	16.3	6.3
	3	SN	145	91	14.2	16.0	5.1	1.8	8.2	10.9	8.1
30.3cm	4	CL	170	81	15.2	17.8	8.1	2.6	7.1	9.9	9.6
shoe	5	CL	185	88	11.0	16.7	7.0	5.7	10.4	9.7	7.6
J.M.	1	SN	137	74	14.5	24.8	3.6	10.4	1.1	21.2	12.7
110Kg	2	SN	145	78	13.7*	24.0	4.3	10.3	5.0	19.7	12.6
	3	SN	155	84	13.0*	24.4	3.6	11.4	2.4	20.8	11.6
	4	CL	155	70	11.6	18.9	3.3	7.3	3.4	15.6	10.4
	5	CL	165	75	13.4	24.2	6.2	10.8	2.4	18.0	10.5
	6	CL	170	77	13.2	24.0	6.3	10.8	3.0	17.7	11.5
M.M.	1	SN	130	69	13.8	23.1	7.6	9.3	12.7	15.5	13.8
+110Kg	2	SN	145	77	14.3	29.0	8.7	14.7	13.7	20.3	17.4
	3	SN	155	83	12.7	24.8	8.3	12.1	10.9	16.5	11.9
32.0cm	4	CL	170	80	13.7	28.0	8.8	14.3	8.0	19.2	18.7
shoe	5	CL	185	87	15.4	28.8	10.2	13.4	10.4	18.6	19.3
J.H.	1	SP	130	81	13.7	16.5	2.0	2.8	---	14.5	---
+110Kg	2	SP	140	88	13.8	19.3	2.4	5.5	---	16.9	---
	3	SP	150	94	11.0	15.2	0.0	4.2	---	15.2	---
	4	CP	160	84	10.6	16.0	4.9	5.4	---	11.1	---
	5	CP	180	95	12.8	15.2	6.2	2.4	---	9.0	---
	6	CP	200	105	11.3	14.8	4.9	3.5	---	9.9	---

A: CP position in cm from front of foot toward heel at lift off
B: CP position in cm from front of foot toward heel at end of first pull
C: CP position in cm from front of foot toward heel at end of second pull
D: backward displacement of CP (B-A) during first pull
E: backward displacement of bar during first pull
F: forward displacement of CP (B-C) during second pull
G: forward displacement of bar during second pull
SN: snatch; SP: snatch pull; CL: clean; CP: clean pull/center of pressure
* data collection started just after lift off, actual value likely to be slightly greater

A specially designed program permitted continuous input of the data from initiation until stopped, when only the final two seconds of data collected remained in memory. This design avoided the necessity of guessing when the athlete was about to begin his lift ("lift-off"). Data collection was stopped at the appropriate point during the lift, with the previous two seconds of data being more than sufficient to cover the start of the lift. Immediately after each trial the three parameters were displayed as a function of time on a monitor to check that data collection was successful. The data was then stored on floppy disk and later printed for analysis (e.g. Figures 1 and 2). Data was analyzed to find CP location at "lift-off", and its maximum posterior and anterior position during the pulling phases of the lifting movement. Maximal displacement of the bar toward and away from the athlete's body was determined from the Selspot data, and compared to CP movements both temporally and in magnitude. Figures 3 and 4 show magnified views of the horizontal bar movement (LX) section of Figures 1 and 2 respectively. Movable marker lines were set at key points for measurements from the data record. For example, in Figure 3 marker #5 was set at bar lift off (see vertical bar movement (LY) record in Figure 1) and its horizontal position is given under LX #5. Marker #4 gives maximal backward bar position and #1 maximal forward position. In some cases the boundary values of the display "box" provided the extreme position values (e.g. Figure 4, -0.229 and -0.088). Caibration of Selspot diode movement was accomplished using standard methods. Accuracy of CP position on the force plate was checked by applying force to known points on the plate. The athletes positioned themselves on the 60 by 40 cm plate within a centered rectangle 56 by 36 cm, with the front edge of their shoes at one side (Figures 5-8). CP position was measured as centimeters behind this side of the rectangle, which was equivalent to centimeters back from the front edge of the shoes.

RESULTS AND DISCUSSION

Table 1 lists the snatch or snatch pull and clean or clean pull attempts of each subject relative to actual weight lifted and percentage of the subject's best snatch or clean. Columns A, B and C give the center of pressure (CP) location in centimeters behind a line connecting the front edges of the athlete's shoes (Figures 5-8) at lift-off, finish of the first pull (bar reaching knee height), and finish of the second pull (bar reaching maximum velocity), respectively. Note the consistency in CP position for a given athlete during a given type of lifting movement. Subject D.A. has a maximum difference of 0.6 cm for all tials in lift off position, J.M. has a maximum difference of 0.8 cm at the end of the first pull for all three snatch lifts, and J.H. has a maximum difference of 1.3 cm at the end of the second pull for all three clean pulls. Generally, for a given athlete and a given movement, CP position differences are less than two centimeters with few exceptional cases over five centimeters. Lift off CP positions were the most

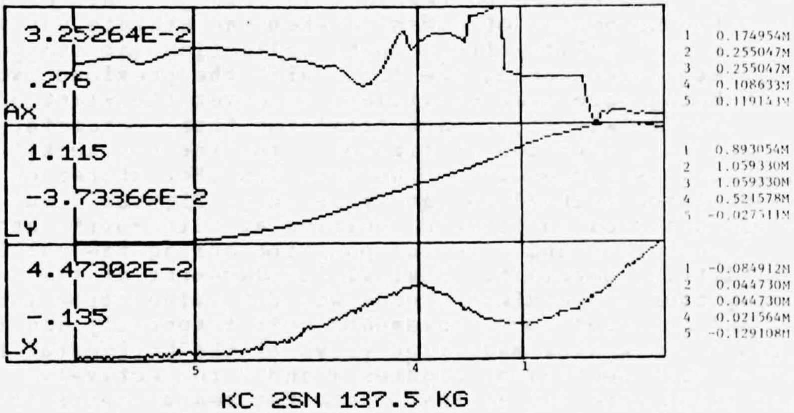


FIGURE 1: Sample data output from computer. AX: Front - Back Balance Position, LY: Vertical Bar Position, LX: Horizontal Bar Position, #5: Lift-Off, #4: Maximum Backward Bar Position During First Pull, #1: Maximum Forward Bar Position During Second Pull. NOTE: Numbers in each box are values at the top and bottom edges.

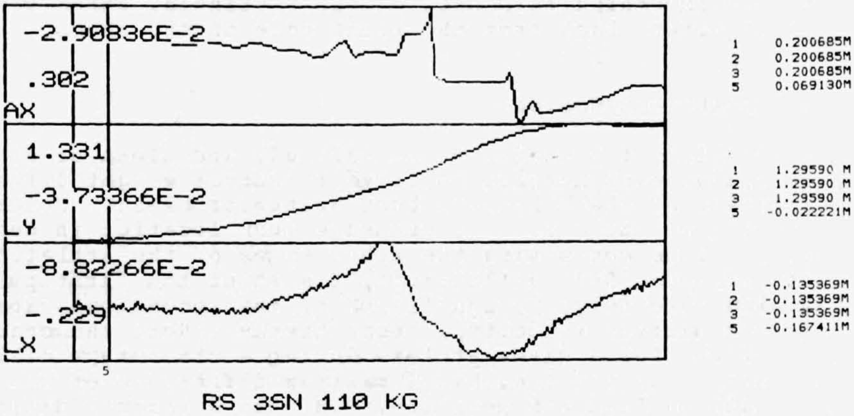
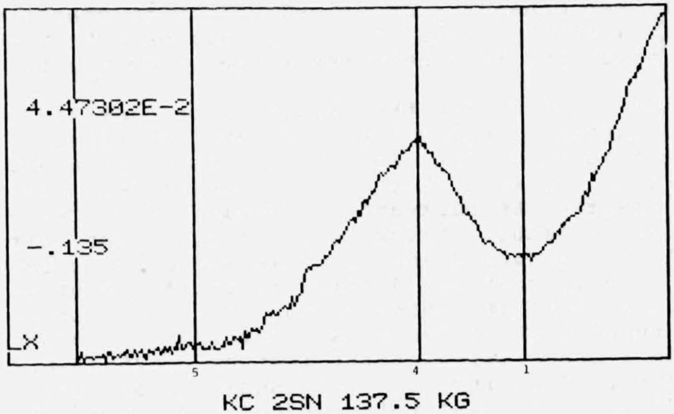
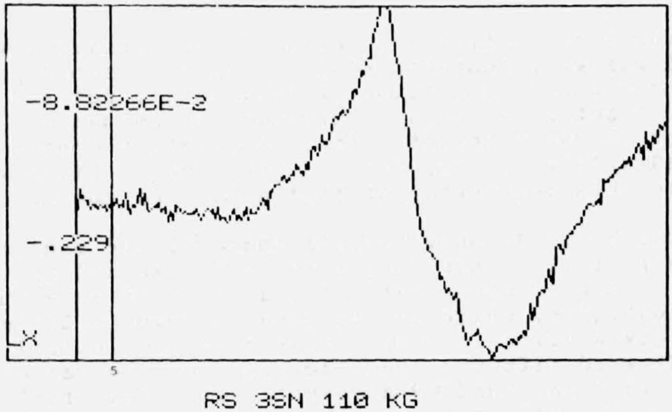


FIGURE 2: Sample data output from computer. (Lables same as Figure 1.)



LX		LY		AX	
1	-0.084912M	1	0.893054M	1	0.174954M
2	0.044730M	2	1.05933 M	2	0.255047M
3	0.044730M	3	1.05933 M	3	0.255047M
4	-0.021564M	4	0.521578M	4	0.108633M
5	-0.129108M	5	-0.027511M	5	0.119143M

FIGURE 3: Magnification of LX box from Figure 1.



LX		LY		AX	
1	-0.135369M	1	1.29590 M	1	0.200685M
2	-0.135369M	2	1.29590 M	2	0.200685M
3	-0.135369M	3	1.29590 M	3	0.200685M
5	-0.167411M	5	-0.022221M	5	0.069130M

FIGURE 4: Magnification of LX box from Figure 2.

consistant, with R.S.'s snatches a notable exception. These same snatches all resulted in CP positions slightly in front of the reference line at the finish of the second pull. This most likely was caused by unnoticed shifts in starting foot placement. Note that trial 2 of R.S. had only forward CP movement, resulting in a negative value in column D.

Columns D and E list the magnitude of backward movement of the CP and barbell, respectively, during the first pull. The single negative value in column D was discussed above. In general, it can be seen that for a given athlete and type of lift, the greater the backward CP movement the greater the backward bar movement. Values are not given for snatch or clean pulls in columns E and G. This was done to focus attention on only complete lifting movements, from which the most pertinent coaching information can be generated. A linear regression of column E as a function of column D resulted in a correlation coefficient of 0.626 (E=6.25 + 0.35 D, n=16). This included only snatches or cleans (no pulls), eliminating completely subject J.H. Subject J.M. was also not included in the regression. Data from film analysis of 20 of his lifts in five meets showed that backward bar displacement during the first pull increased with weight lifted to values of about 12 cm for his heaviest snatches, and about 8 cm for his heaviest cleans. These displacements are much greater than found in column E for his lifts in this study, which averaged only 76% of maximum. Thus, the data was not representative of his normal performance and was eliminated from the regression. This discrepancy did not occur for the other four subjects included in the regression.

Columns F and G list the magnitude of forward movement of the CP and barbell, respectively, during the second pull. No clear trend can be seen, although substantial forward movements occurred for both. A linear regression of column G as a function of column F resulted in a correlation coefficient of 0.460 (G=4.15 + 0.55 F, n=16). The same 16 lifts were included in this regression as that discussed above.

Figures 9 and 10 show typical temporal and magnitude relationships between horizontal barbell (LX) and CP (AX) movements. Each of these variables is plotted as a function of bar height (LY), which can be used to compare LX and AX at any given point in time. Note that the initial backward (toward lifter's body) movement of the bar corresponds temporally with backward CP movement. In a few trials (e.g. Figure 10) slight forward bar and/or CP movement occurs briefly just after "lift off". Also note that later initiation of forward CP movement precedes initiation of forward bar movement. As the bar approaches its maximum height horizontal movement diminishes. This was generally preceeded by a period of fairly consistent CP position (e.g. Figure 10). Most AX versus LY records show a very sudden CP shift backward prior to the

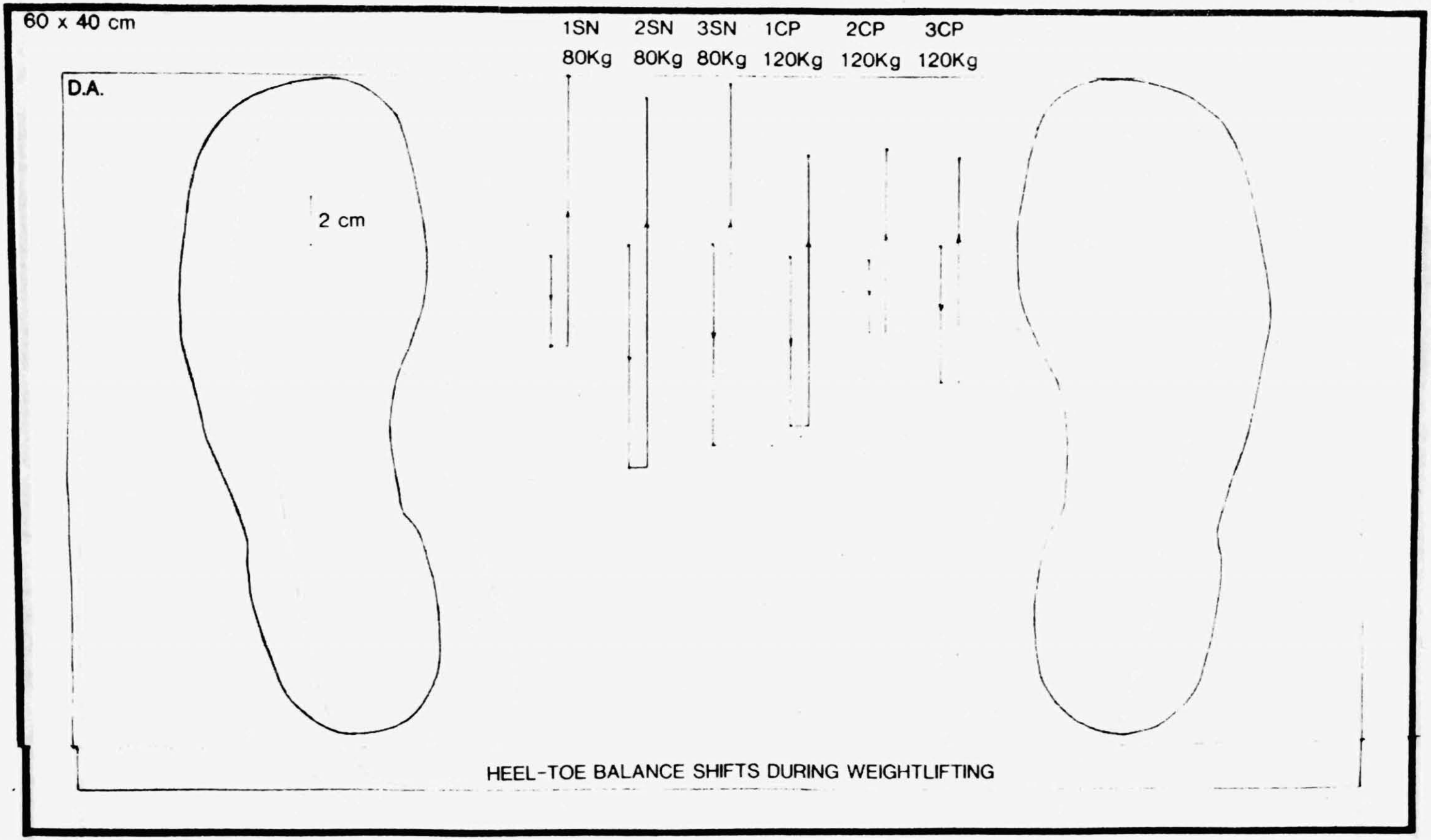


FIGURE 5: Sample foot placement and balance shift diagram. The first point is front-back balance position at lift-off, the second point is balance location at the end of the first pull, the third point is balance location at the end of the second pull, for each attempt plotted. Right-left position is irrelevant in the illustration.

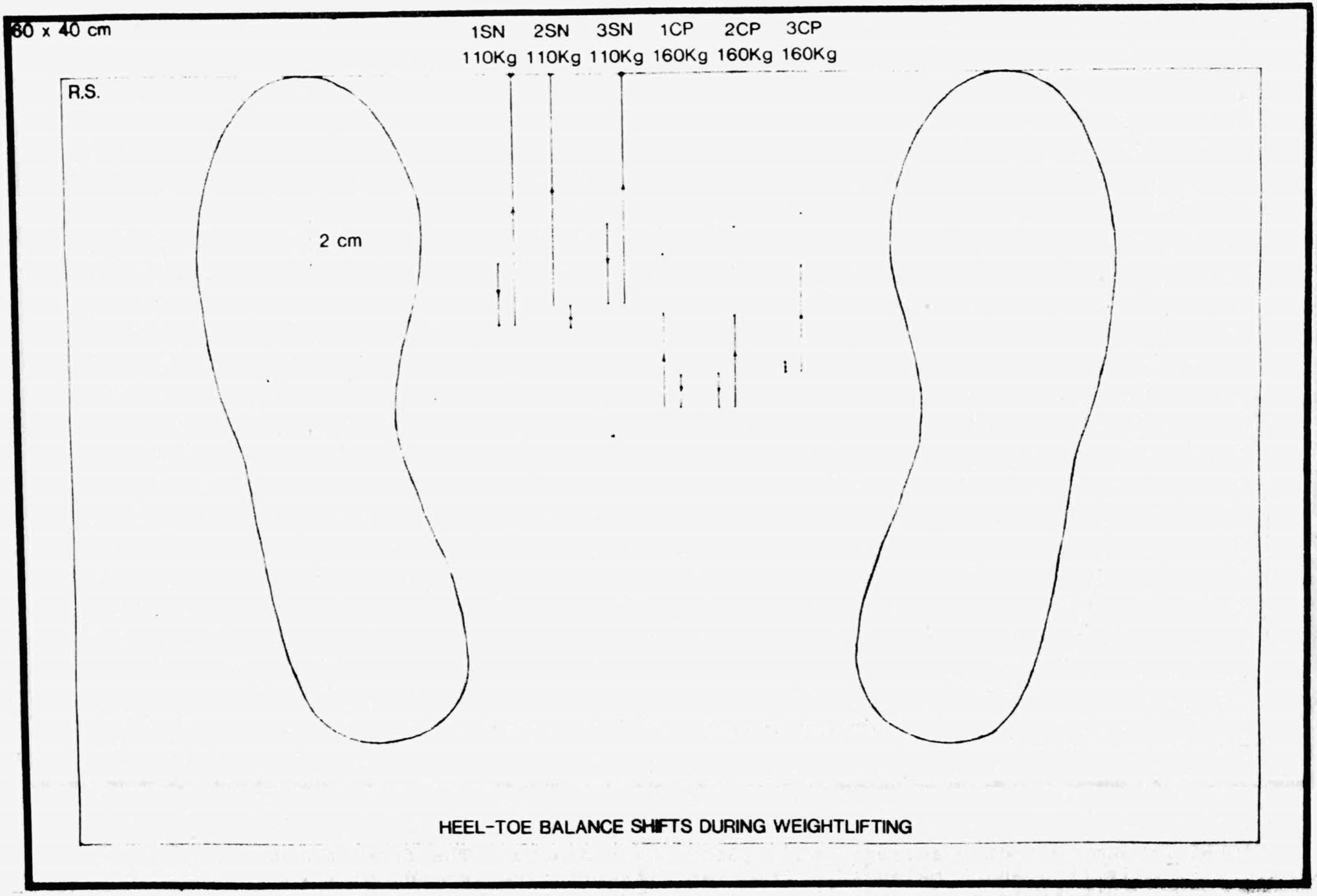


FIGURE 6: Sample foot placement and balance shift diagram. (see Figure 5.)

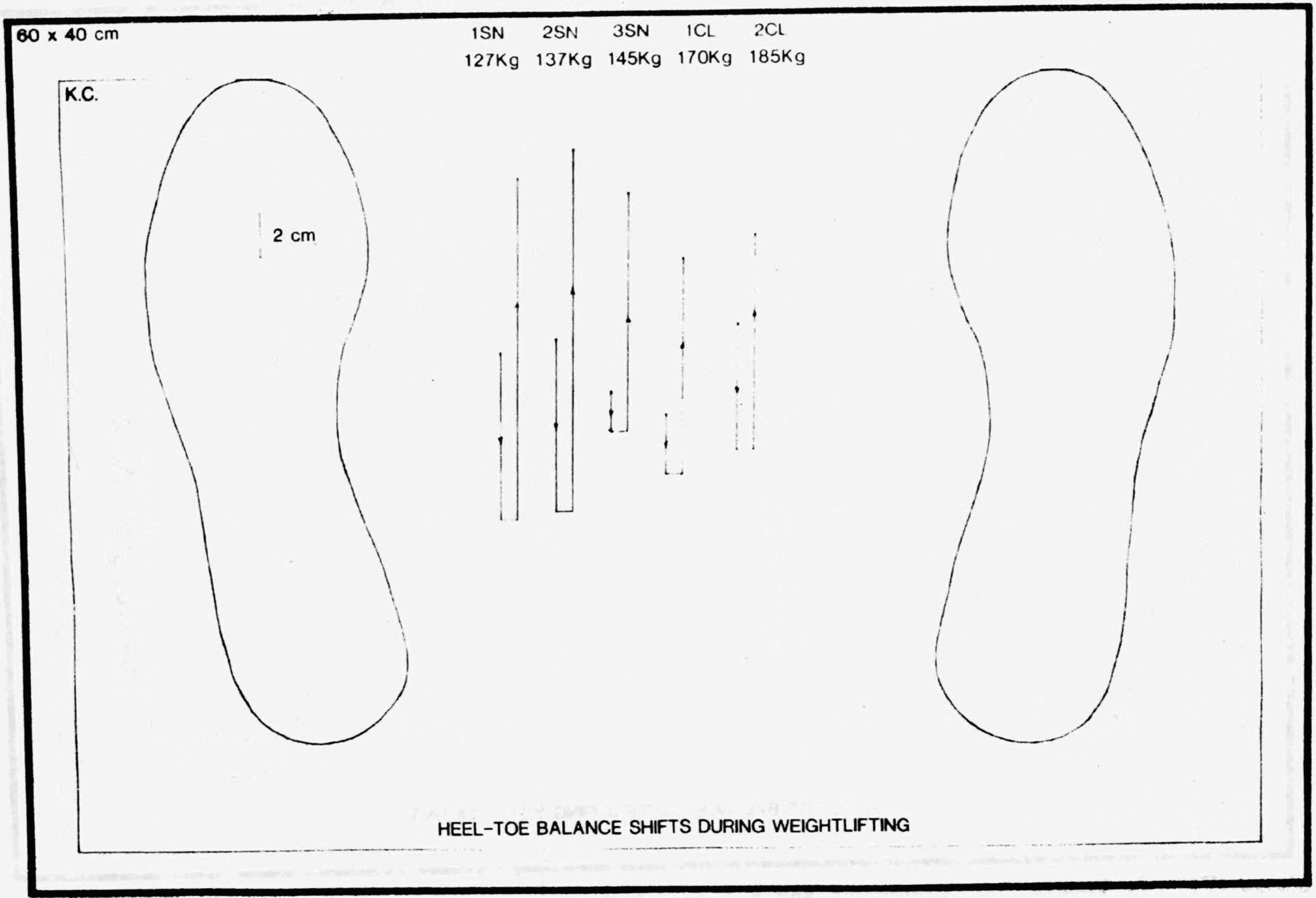


FIGURE 7: Sample foot placement and balance shift diagram. (see Figure 5.)

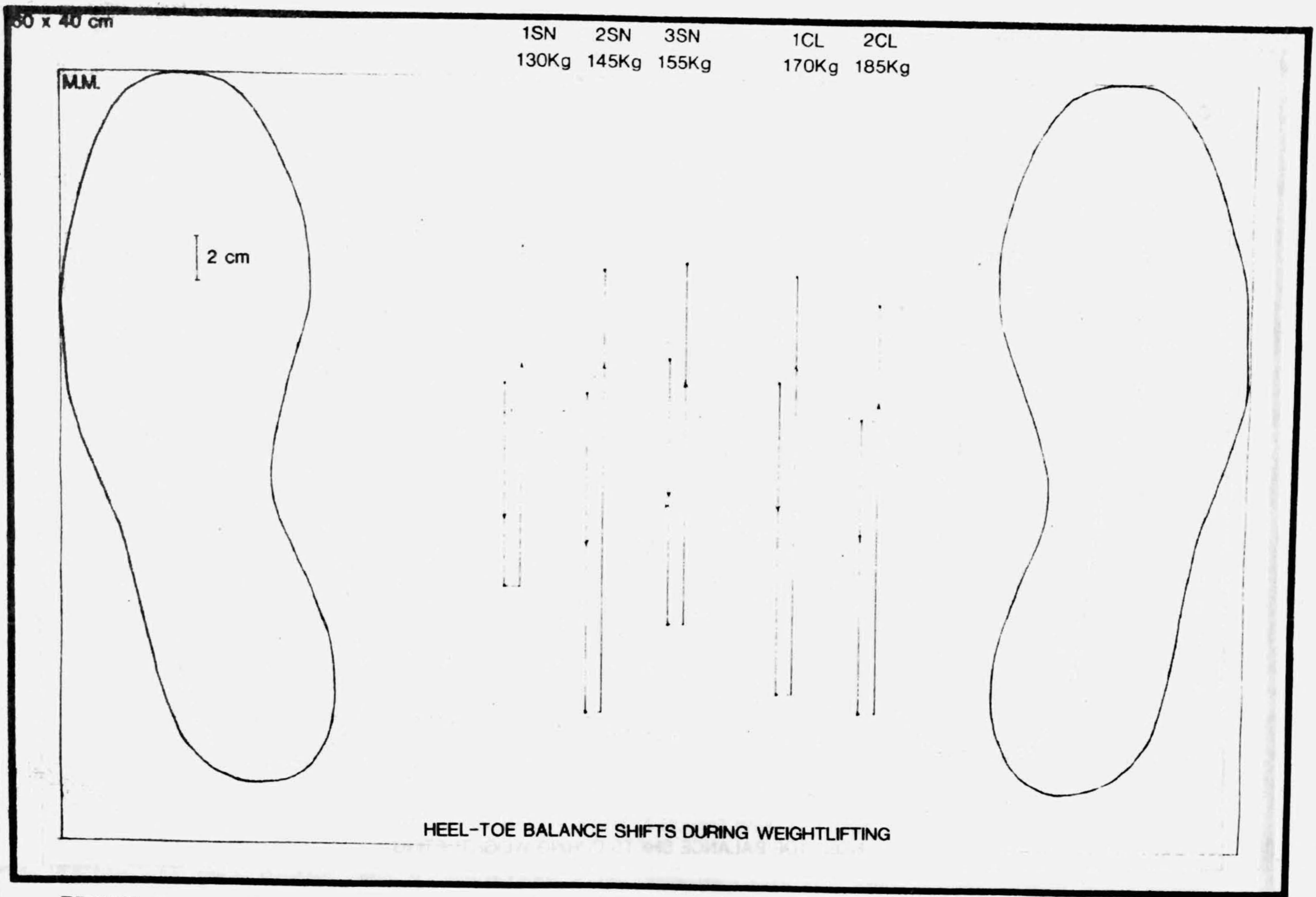
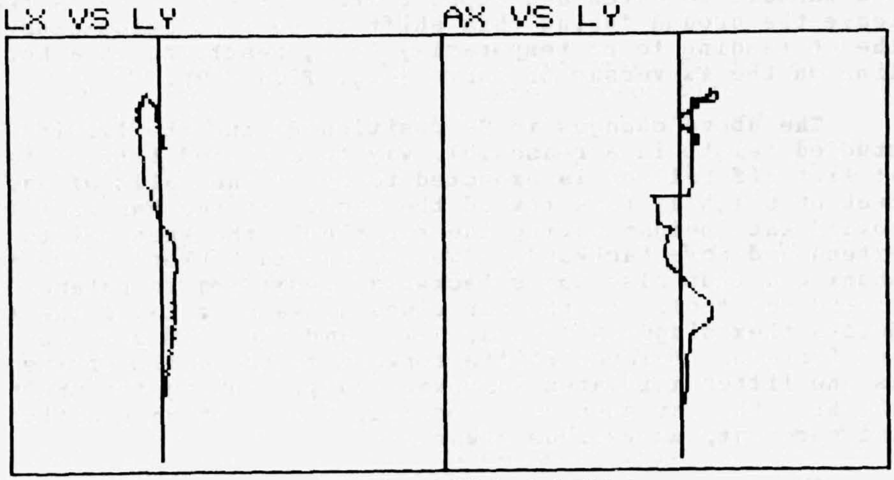
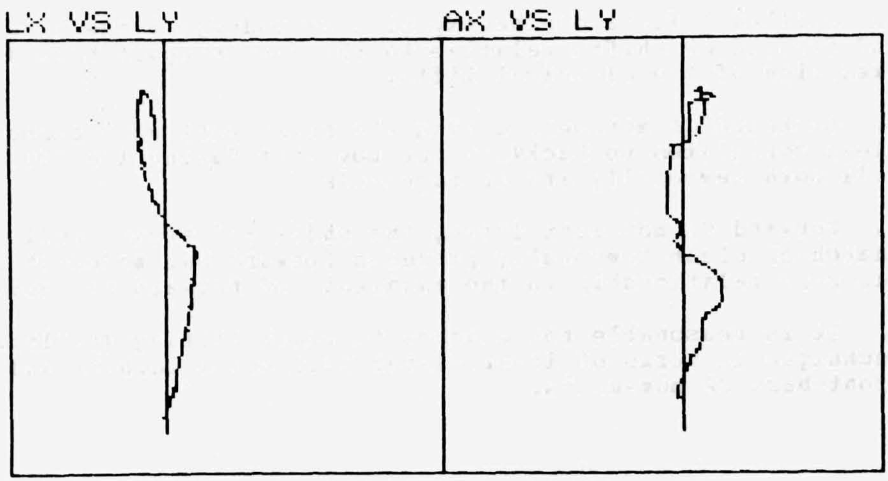


FIGURE 8: Sample foot placement and balance shift diagram. (see Figure 5.)



J.M. 2SN–145Kg

FIGURE 9: Sample bar trajectory plot (LX vs. LY), and horizontal (front-back) balance (AX) vs. bar height (LY) plot.



M.M. 2CL–185Kg

FIGURE 10: Sample bar trajectory plot (LX vs. LY), and horizontal (front-back) balance (AX) vs. bar height (LY) plot.

bar reaching maximum height. This occurs just after the bar reaches maximum velocity, when the athlete shifts his body under the barbell to catch and support it. Often a lifter's feet will leave the ground during this shift of body position causing the CP reading to be temporarily lost, resulting in a horizontal line on the Ax versus LY curve (e.g. Figure 9).

The above changes in CP position during the lifting movements studied relate in a reasonable way to accepted lifting technique. At lift off balance is expected to be on the balls of the feet or slightly back toward the arch. As the bar is lifted toward knee height during the first pull the knee joints extend and move backward. The bar should be kept close to the shank and thus also moves backward, resulting in balance shifting toward the heel. As the bar rises above knee level the knee joints flex slightly (Enoka, 1979) and the hips move downward and forward. Balance shifts forward to the balls of the feet as the lifter initiates an upward jump. During the shift of the hips the bar must move forward, due to thigh position and movement, as well as upward.

The extent of CP movement during each lift is evident in Figures 5-8, as well as Table 1. M.M., for example, had a backward CP movement of 12.1 cm or 38% of shoe length for his heaviest snatch, and 13.4 cm or 42% of shoe length for his heaviest clean. His forward CP shifts for these lifts were 16.5 cm (52%) and 18.6 cm (58%), respectively.

CONCLUSIONS

1. Skilled lifters can be expected to undergo large backward and forward CP shifts relative to the foot support base during execution of the classical lifts.

2. Backward CP movement during the first pull of a snatch or clean correlates to backward bar movement during the first pull both temporally and in magnitude.

3. Forward CP movement during the shift and second pull of a snatch or clean temporally precedes forward bar movement and has some relationship to the magnitude of forward bar movement.

4. It is reasonable for coaches to teach lifting (pulling) technique in terms of interrelated horizontal barbell and front-back CP movements.

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