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Case study

An ergonomic evaluation of steel and composite access covers

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Abstract

Twenty males and 20 females participated in a study undertaken to provide an ergonomic basis for deciding between the conventional steel access cover (less expensive and heavier, and therefore undesirable) and a new composite access cover (relatively more expensive but lighter, and therefore more desirable). The results indicated that the conventional steel cover (weighing 80.35 kg and 91.44 cm in diameter) is too heavy for safe manual handling. The steel cover weight not only exceeded the average individual psychophysical lifting capacity of males and females (33.83 kg and 29.56 kg, respectively), it exceeded the average psychophysical lifting capacity of two-member male and female teams as well (76.04 kg and 67.08 kg, respectively). The spinal compression, if lifting the steel access cover was permitted, would have been approximately 13210 N for individual lifting and 6190 N for team lifting. Only 4 males were able to lift the composite access covers (weighing 38.13 kg and 91.44 cm in diameter) straight up using built-in handles, individually. The average spinal compressive force generated in this case (5849 N) also exceeded the spinal column strength of most males and females. Lifting the composite cover by a two-person team was found to be much safer (average spinal compression for team lifting the composite cover = 2501 N) and is a viable solution. The factor of safety for team lifting the composite access cover is at least 36% for females and 56% for males. Removing the composite cover individually using a rod type handle (unseating the cover by first rotating it and then pulling it for removal) resulted in somewhat greater physical stress (21.33 kg vertical force and 2898 N spinal compressive force) than lifting it by a team but, on the average, provided a factor of safety of at least 49% for males and 26% for females. Removing the composite access cover with the aid of the rod handle was also perceived to be "light" (average RPE value of 10.25 for males and 10.00 for females).

Relevance to industry

This paper presents a case study describing the use of ergonomics principles in evaluating two different product designs. The methodology demonstrates how ergonomics may be used in "selling" the benefits of an obvious but expensive solution to a problem.

Keywords: Access cover; Psychophysical lifting capacity; Maximum acceptable weight of lift; Spinal compression; Spinal column strength

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1. Introduction

Ergonomists frequently encounter situations that require them to "sell" their solution to the management personnel who are unaware of ergonomics and its significance. Since in many such cases, the proposed solution is, or may be, more expensive, the ergonomist must demonstrate that the incremental cost of the proposed solution provides benefits that are essential for the health and safety of the workers and otherwise would not be realized. This case study deals with such a scenario in the petrochemical industry.

Openings to underground passages, confined spaces, and underground submerged storage tanks are generally covered by steel access covers that are removed and replaced manually to allow routine maintenance and service activities. These access covers vary in diameter from 0.91 m to 1.067 m and weigh upwards of 80 kg and must be lifted clear and away from their seat when removed. As the situations in the field frequently do not allow mechanical aids to be used and a second person may not always be available to assist the individual, lifting the heavy steel access cover by an individual, unaided, makes the task extremely hazardous. There are also occasions when several access covers, placed in a cluster, must be removed and replaced at the same time. The added frequency of handling further increases the potential for serious injuries.

Traditionally, petrochemical industries have used steel access covers. Given that a newly designed and much lighter access cover made out of composite material is available, albeit at almost twice the cost, the decision that a buyer must make is whether to pay more for the composite access cover or continue using the traditional steel access cover. The task of an ergonomist is to convince users that it is in their interest to choose the lighter cover. A lighter access cover, even though more expensive, will pay off by reducing the costs associated with injuries that are incurred when objects weighing beyond the load-handling ability of the industrial population are handled.

This case study was carried out with the overall purpose of quantifying the physical stresses resulting from lifting the steel access cover and the improved composite access cover conventionally and with the aid of a rod type handle (Fig. 1). The intent was to demonstrate that the use of a steel access cover would create physical stresses beyond the capacity of the workforce (Mital et al., 1993). It was reasoned that once the users see the overall benefits of using the composite access cover, initial cost differential would not be their major concern.

In order to achieve the overall objective, the following specific objectives were outlined:

(1) To determine the population's capacity for lifting objects which have the same diameter and shape as the steel and composite access covers.
(2) To determine the lifting capacities of unmatched two-people teams (M-M and F-F).
(3) To determine how the weights of steel and composite access covers compare with the individual and team lifting capacities.
(4) To determine if the unmatched two-person team is a viable solution for removing and replacing access covers.
(5) To determine physical stresses in the following cases:
    (a) lifting the steel access cover – alone and in team (team members unmatched).
    (b) lifting the composite access cover – alone and in team (team members unmatched).
    (c) lifting individual and team MAWL (team members unmatched).
(6) To determine how the conventional lifting by individuals compares with the suggested technique (access cover removal with a rod type handle) as far as the perceived exertion and physical stresses are concerned.
(7) To determine the specific advantages of using the composite access cover and removing and replacing it with a rod type handle.

2. Methods

An experiment was designed and conducted in order to meet the outlined objectives. The experiment involved participation of male and female

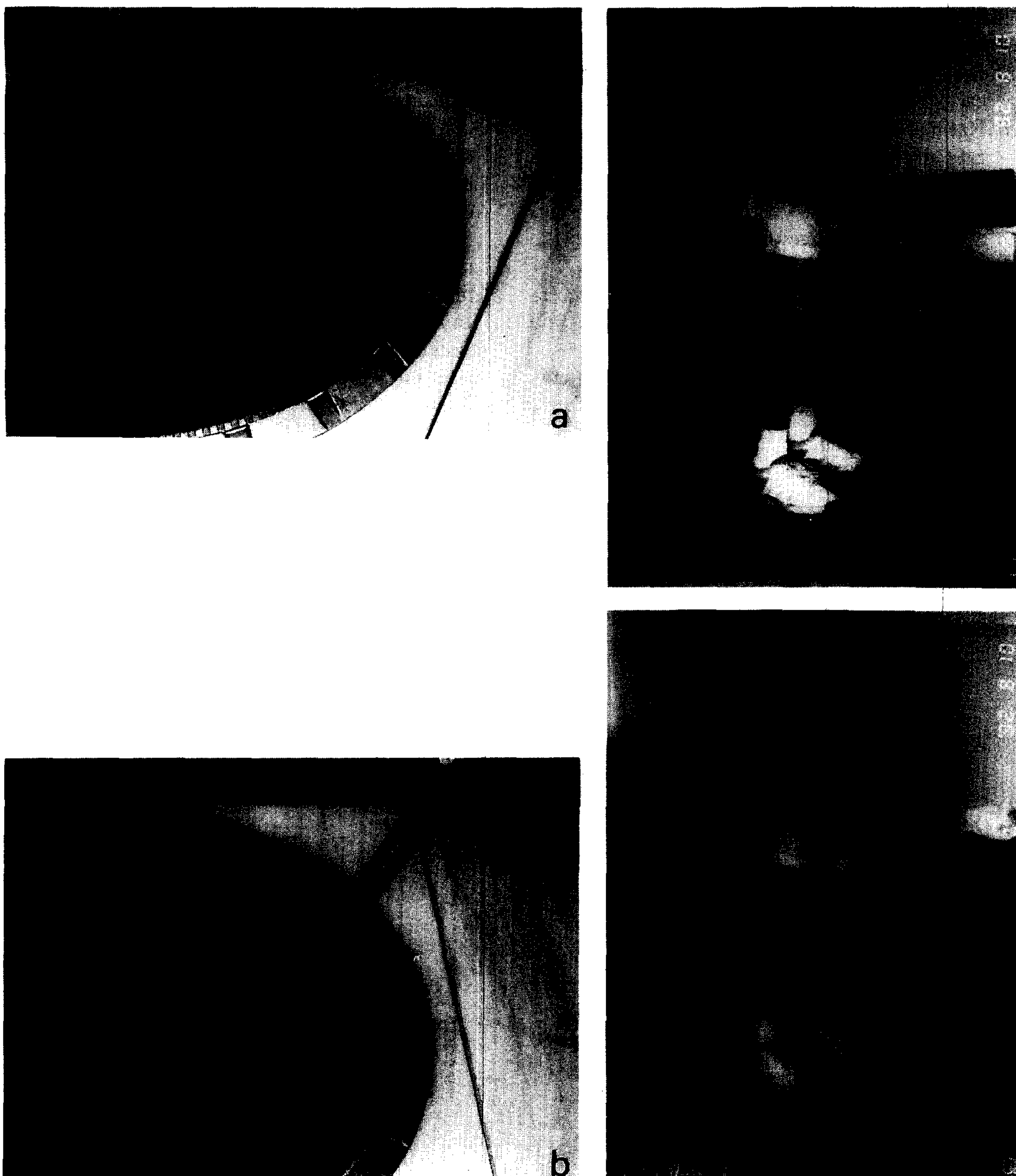

Fig. 1. Sequence showing removal of the composite access cover with a rod handle.

volunteers, individually and in teams of two (males or females), and determination of:
(1) The isometric back strengths of individuals and unmatched teams (M-M; F-F).
(2) Individual and unmatched team psychophysical capacities (M-M; F-F).
(3) Ratings of perceived exertion (RPE) and heart rate during the removal of access covers in case the psychophysical lifting capacities exceeded the weights of the access covers.
(4) Spinal compressive forces while lifting the access covers individually or in a team.
(5) RPE values when lifting the composite access cover and when removing it with the rod handle.
(6) RPE values and heart rate when access covers and MAWL were lifted five times, successively.

2.1. Subjects

Twenty males and 20 females voluntarily participated in the study. The forty subjects formed 20 2-member teams (10 male teams and 10 female teams). All participants were required to complete personal data and consent forms. Only those subjects who were healthy, had no history of any back ailment and were not on medication participated in the experiment. During the experiment, subjects wore work shoes and comfortable clothing.

Once the suitability of the individuals to participate in the experiment was established, a number of body size measurements were made on each individual for the purpose of establishing the sample population profile. The body size measurements were made in accordance with the procedures established by Roebuck et al. (1975). In addition to body size measurements, individual isometric back strength and team isometric back strength were also measured. The procedure outlined by Caldwell et al. (1974) was used in the measurement of isometric back strength. A special handle was built to measure team isometric back strengths (Fig. 2).

Tables 1 and 2 show the distribution of the measurements made for males and females, respectively. The body size and individual isometric back strength values are comparable to those of the industrial population (Mital, 1984).

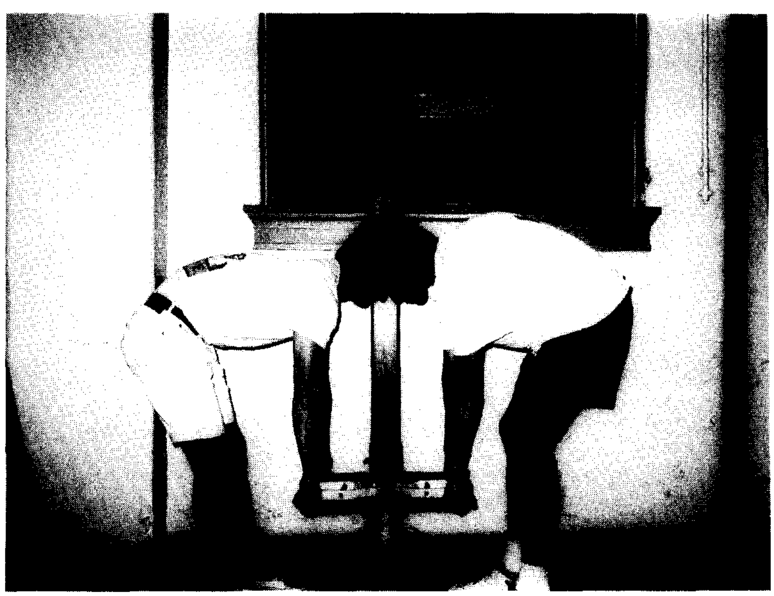

Fig. 2. Measurement of team isometric back strength.

Table 1
Distribution of measurements made on male subjects ($N = 20$)

Attribute	Mean	SD	Range
Age (years)	23.45	3.44	20 – 32
Stature (cm)	177.51	4.48	165.40–183.60
Body weight (kg)	70.65	7.20	57.20– 87.62
Elbow height (cm)	110.85	6.95	93.60–121.10
Knuckle height (cm)	78.24	2.63	74.30– 84.50
Forearm grip dist. (cm)	35.98	1.98	31.70– 40.10
Chest width (cm)	29.69	1.99	26.20– 34.40
Chest depth (cm)	18.94	1.33	16.30– 21.30
Abdominal depth (cm)	17.82	1.85	14.20– 22.50
Standing resting heart rate (bpm)	81.45	11.25	68 – 98
Max. heart rate (bpm) [a]	197.18	2.35	191.28–199.80
Isometric back strength (kg)			
Individual	55.38	15.04	37.07– 85.96
Team	149.07	36.65	95.79–210.04

[a] Maximum heart rate = 214 − (0.71 × age in years).

2.2. Experimental procedure

The experimental procedure involved determination of the following:

(1) Individual psychophysical lifting capacity (MAWL).
(2) RPE at the MAWL.
(3) Team psychophysical lifting capacity (MAWL).
(4) Team RPE at the MAWL.
(5) RPE at the end of 5 consecutive lifts of individual and team MAWL (self-paced).
(6) Heart rates at the end of 5 consecutive lifts of individual and team MAWL (self-paced).
(7) Proportion of team MAWL lifted by each member.
(8) Individual and team RPE for single lift of 38.13 kg (the weight of the composite access

Table 2
Distribution of measurements made on female subjects ($N = 20$)

Attribute	Mean	SD	Range
Age (years)	24.70	5.15	18.00– 38.00
Stature (cm)	164.82	4.98	154.60–172.30
Body weight (kg)	58.90	6.70	49.94– 72.18
Elbow height (cm)	106.63	7.62	98.30–133.30
Knuckle height (cm)	74.42	3.68	66.70– 82.80
Forearm grip dist. (cm)	32.03	2.07	29.40– 36.60
Chest width (cm)	26.79	1.13	24.80– 28.60
Chest depth (cm)	17.90	1.66	14.70– 21.00
Abdominal depth (cm)	15.72	1.62	13.10– 18.90
Standing resting heart rate (bpm)	79.65	11.32	53.00– 98.00
Max. heart rate (bpm) [a]	195.88	4.10	186.00–198.00
Isometric back strength (kg)			
Individual	36.22	10.37	19.52– 65.22
Team	91.22	17.95	50.02–113.50

[a] Maximum heart rate = 214 − (0.71 × age in years).

cover) weight in the access cover size container if the individual and/or team MAWL exceeded 38.13 kg.

(9) Individual and team RPE for 5 consecutive lifts (self-paced) of 38.13 kg weight in the access cover size container if the individual and/or team MAWL exceeded 38.13 kg.

(10) Individual and team heart rates for 5 consecutive lifts (self-paced) of 38.13 kg weight in the access cover size container if the individual and/or team MAWL exceeded 38.13 kg.

(11) RPE for removing the composite access cover with the rod handle once.

(12) RPE and heart rate for removing the composite access cover with the rod handle 5 consecutive times.

(13) The vertical force exerted in removing the composite access cover with a rod handle.

From these measurements, the following were calculated:

(1) Proportion of the team MAWL lifted by each member of the team.

(2) Spinal compressive forces during individual and team lifting.

(3) Spinal compressive forces when removing the composite access cover with the rod handle and conventionally lifting (straight up) the composite and steel access covers either individually or in a team.

The modified psychophysical approach (Ayoub and Mital, 1989) was used to determine the maximum weights of lift acceptable to individuals and teams. Members of the team were not matched in any way – by height or body weight or isometric back strength, etc. The subjects, or teams, were randomly started with either a very heavy or very light load in a specially built fiberglass container. The diameter and shape of the fiberglass container were the same as those of the steel and composite access covers. The fiberglass container was fitted with two fixed handles to duplicate the design of steel access covers. The distance between the handles was the same as for the steel access cover. Subjects were allowed to adjust the weight in the container (remove some weight from the weight already in the container or add some more weight to it) in order to arrive at the maximum acceptable weight of lift (MAWL – psychophysical lifting capacity). Fig. 3 shows the fiberglass container, the location of the handles, and a male team attempting to determine its MAWL.

Once the MAWL was reached, the Borg scale

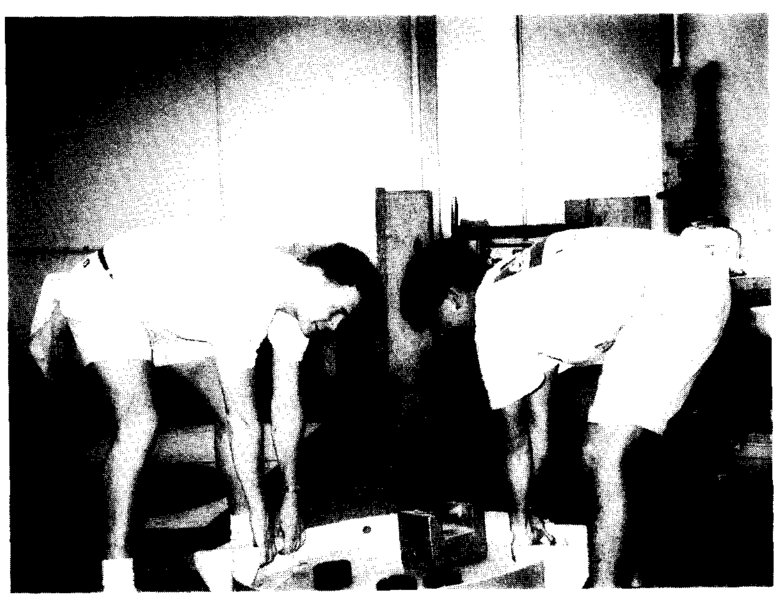

Fig. 3. Determination of team MAWL.

(6–20 scale) was used to record the rating of perceived exertion (Borg, 1985). The heart rates at the MAWL were measured with the help of two Polar Heart Rate Monitors (oxygen consumption was also recorded initially but since it never stabilized due to the very short duration of lifting, few seconds for a single lift to about 45 seconds for 5 consecutive lifts, it was discarded).

If the individual or team lifting capacity exceeded 38.13 kg, the weight of the composite access cover, subjects and teams were asked to lift 38.13 kg in the fiberglass container. RPE values and heart rates for both single lift and 5 consecutive lifts were recorded. This step was not repeated for the 80.35 kg weight, the weight of the steel access cover, even though in some cases the team MAWL exceeded 80.35 kg as it was considered extremely hazardous for either individual or team lifting (Mital et al., 1993).

The spinal compressive forces for the various loads lifted were determined from the 3-D dynamic biomechanical model developed by Kromodihardjo and Mital (1986, 1987). The factors of safety were estimated from the ultimate spinal column strength data provided by Jäger and Luttmann (1991). It should be noted that spinal tolerance for compressive forces provided by Jäger and Luttmann are for static loading conditions. Since the tissue tolerance under dynamic conditions are not known and it was felt that some measure of factor of safety would be important, even though it may not be very accurate, comparison of estimated spinal compressive forces with spinal tolerance under static conditions was undertaken. The factor of safety was defined as the difference between average spinal tissue tolerance under static conditions (A) and estimated spinal compression (B) divided by average spinal tissue tolerance under static conditions (= (A-B)/A). The average spinal tissue tolerance under static conditions was 5700 N and 3900 N for males and females, respectively.

Table 3
Summary of response measurements for males (20 individuals and 10 two-member teams)

Response	Mean	*SD*	Range
Individual MAWL (kg)	33.83	6.21	21.33– 49.48
Individual RPE	13.05	1.10	12.00– 16.00
Individual spinal compression (N)	5081	1059	2897 –7815
Team MAWL (kg)	76.04	17.49	54.48– 108.50
MAWL shorter member (kg)	39.17	7.99	27.05– 53.89
MAWL taller member (kg)	36.86	9.16	27.42– 54.89
Team RPE	12.40	1.53	7.00– 14.00
Spinal compression for team lifting (N)			
Shorter member	6090	1599	3958 –8704
Taller member	5608	1396	3895 –8581
Individual RPE for lifting MAWL 5 times	14.60	1.57	12.00– 17.00
Individual heart rate for lifting MAWL 5 times	122.30	16.41	96.00– 170.00
Team RPE for lifting team MAWL 5 times	13.45	1.28	10.00– 15.00
Average team heart rate for lifting team MAWL 5 times	116.65	13.03	92.00– 150.00
Individual RPE for lifting 38.13 kg once ($N = 4$)	12.50	1.00	11.00– 13.00
Team RPE for lifting 38.13 kg once	8.95	1.79	6.00– 11.00
Individual RPE for lifting 38.13 kg 5 times ($N = 4$)	12.75	1.26	11.00– 14.00
Heart rate for lifting 38.13 kg 5 times, individually ($N = 4$)	127.50	25.59	102.00– 163.00
Team RPE for lifting 38.13 kg 5 times	9.75	1.99	6.00– 12.00
Average team heart rate for lifting 38.13 kg 5 times	106.95	13.79	83.00– 144.00
RPE for removing composite cover with the rod once (individually)	10.25	1.86	6.00– 12.00
RPE for removing composite cover with the rod 5 times (individually)	10.75	2.36	6.00– 15.00
Heart rate for removing composite cover with the rod 5 times (individually)	107.10	14.56	80.00– 134.00

Since stature of team members influences the angle of the load with respect to the horizontal and thereby the proportion of load on each individual, the proportion of MAWL lifted by each member of the team was determined by adjusting the team MAWL in proportion to team members' height; the shorter member lifting more than the taller member. The vertical force necessary to remove the unseated composite access cover was measured by a load cell.

3. Results

The values of different responses measured during the experiment are summarized in Tables 3 and 4 for males and females, respectively. The various male and female responses were statistically compared using a t-test. The results of most relevant comparisons are discussed below.

3.1. Individual and team isometric back strengths

Males, as expected, had significantly higher back strength than females (average 55.38 kg for males versus average 36.22 kg for females) ($p < 0.01$). Males also exerted significantly more force in teams than females (average 149.07 kg for male teams versus average 91.22 kg for female teams) ($p < 0.01$). Furthermore, in teams, both males and females on the average exerted more than 2.5 times more force than individual exertions ($p < 0.01$). The individual back strengths of both males and females were significantly lower than the weight of the steel access cover (80.36 kg) ($p < 0.01$). Furthermore, the average back strength of females was also significantly lower than the weight of the composite access cover ($p < 0.01$), but significantly higher ($p < 0.01$) than the vertical force exerted when removing the composite access cover with the rod handle (21.34 kg). The average team back strengths of both

Table 4
Summary of response measurements for females (20 individuals and 10 two-member teams)

Response	Mean	SD	Range
Individual MAWL (kg)	25.29	4.99	19.52– 36.77
Individual RPE	13.35	0.99	11.00– 16.00
Individual spinal compression (N)	3592	851	2580 –5594
Team MAWL (kg)	59.56	6.84	48.12– 72.64
MAWL shorter member	31.01	3.59	21.92– 38.53
MAWL taller member	28.54	3.20	21.02– 34.10
Team RPE	12.85	1.63	11.00– 17.00
Spinal compression for team lifting (N)			
Shorter member	4586	627	3745 –5899
Taller member	4154	559	2997 –5125
Individual RPE for lifting MAWL 5 times	14.50	2.11	8.00– 17.00
Individual heart rate for lifting MAWL 5 times	120.90	16.13	86.00– 158.00
Team RPE for lifting team MAWL 5 times	13.20	1.88	11.00– 18.00
Average team heart rate for lifting team MAWL 5 times	109.10	12.95	80.00– 136.00
Team RPE for lifting 38.13 kg once	9.00	1.72	7.00– 13.00
Team RPE for lifting 38.13 kg 5 times	9.75	1.97	8.00– 15.00
Average team heart rate for lifting 38.13 kg 5 times	102.80	12.21	72.00– 123.00
RPE for removing composite cover with the rod handle once (individually)	10.00	1.59	8.00– 14.00
RPE for removing composite cover with the rod handle 5 times (individually)	11.90	1.55	10.00– 17.00
Heart rate for removing composite cover with the rod handle 5 times (individually)	120.40	14.75	92.00– 149.00

males and females, however, were significantly higher than the weight of the steel access cover ($p < 0.01$).

3.2. Individual and team psychophysical lifting capacity (MAWL)

Males, on the average, accepted 33.83 kg weight for lifting in the access cover size container. In comparison, females accepted 25.29 kg weight for lifting in the same container. As in the case of isometric back strength, both male and female teams had significantly higher MAWLs than individual MAWLs ($p < 0.01$). Male teams also had a significantly higher MAWL than female teams (average 76.04 kg for male teams versus average 59.56 kg for female teams) ($p < 0.01$). In male teams, MAWL for the shorter member of the team was approximately 6% more than MAWL for the taller member of the team. The MAWL for the shorter member in the female team was approximately 8% more than MAWL for the taller member of the team. The differences in the weight lifted by team members were significant ($p < 0.01$). Both individual and team MAWLs for males and females were significantly lower than the weight of the steel access cover (80.36 kg) ($p < 0.01$). While the team MAWLs of males and females were significantly higher than the weight of the composite access cover (38.13 kg) ($p < 0.01$), their average individual MAWLs were not ($p > 0.10$). Only 4 of the 20 males had a MAWL exceeding 38.13 kg. The average individual MAWLs of both males and females, however, were significantly higher than the vertical force exerted in removing the composite access cover with the help of the rod handle (21.34 kg) ($p < 0.01$).

3.3. Spinal compression during individual and team lifting

The spinal compressive forces resulting from manual lifting were estimated from the 3-dimensional dynamic biomechanical model developed by Kromodihardjo and Mital (1986, 1987). Tables 3 and 4 show these forces for individual and team MAWL for males and females, respectively. The average spinal compressive force at MAWL for males for individual lifting was 5081 N. For females, the average spinal compressive force at individual MAWL was 3592 N. When lifting MAWL in teams of two, the compressive forces were significantly higher for shorter members of the team than compressive forces for the taller members of the team (average 6090 N for the shorter member of the male teams and 5608 N for the taller member of the male teams versus average 4586 N for the shorter member of the female teams and 4154 N for the taller member of the female teams) ($p < 0.01$). The spinal compressions for both members of the team, however, were significantly higher than spinal compressive forces for individual lifting ($p < 0.01$). This was true for both males and females. Thus, the individuals were subjected to greater spinal stress when lifting MAWL in teams of two than when lifting the individual MAWL alone. The spinal compressive force when removing the composite access cover with the rod handle (vertical force 21.34 kg) was 2898 N. The average compressive force was slightly smaller (2501 N) when the composite access cover weight (38.13 kg) was lifted straight up (conventionally) by two-person teams.

3.4. Ratings of perceived exertion (RPE) for individual and team lifting

Tables 3 and 4 show the average RPE values for individual and team lifting for males and females, respectively. In general, females perceived all tasks to be slightly more demanding than males. The differences between males and females, however, were not significant ($p \geq 0.10$ in all cases except one). Furthermore, both males and females perceived lifting MAWL in teams to be physically as stressful as lifting MAWL alone ($p \geq 01.10$). Lifting MAWL individually 5 times was perceived to be significantly harder than lifting MAWL 5 times in a team ($p < 0.01$). For both males and females, individual and team lifting 38.13 kg (weight of the composite access cover) were perceived to be significantly easier than lifting corresponding MAWLs ($p < 0.01$). Team lifting 38.13 kg either once or 5 times consecutively was perceived least stressful by both males and females. Removing the composite access cover with the help of the rod handle, either once or 5 times consecutively was perceived to be significantly more difficult than lifting 38.13 kg in a team ($p < 0.01$).

Even though the removal of the composite access cover individually with the help of the rod handle was perceived to be more stressful than lifting the composite access cover conventionally in a team, it was considered a "light" task by both males and females. Even when the access cover was removed 5 times consecutively, the task was not perceived to be difficult.

Overall, the results show that both males and females prefer lifting the composite access cover, either conventionally straight up or with the rod handle, than lifting MAWL. This preference applies to both individual and team lifting and to lifting once or 5 times consecutively.

3.5. Heart rates during individual and team lifting

The average heart rates during team lifting were significantly lower than during individual lifting for both males and females ($p < 0.01$). The average heart rates of both males and females were least when lifting 38.13 kg conventionally in a team (Tables 3 and 4). While for males, removing the composite access cover with the rod handle was physiologically as demanding as lifting it conventionally in a team ($p > 0.10$), females found team lifting the composite access cover significantly easier than removing it with the help of the rod handle ($p < 0.01$). Since only males were able to lift the composite access cover alone conventionally, their average heart rate when removing the composite access cover conventionally was compared with the average heart rate when removing the composite access cover with the rod handle. Removal of the composite access cover with the rod handle was physiologically far less demanding than lifting it alone, conventionally (average heart rate of approximately 107 bpm when using the rod versus average heart rate of approximately 127 bpm when lifting conventionally) ($p < 0.01$).

Overall, the differences in average heart rate between males and females, even when statistically significant, were of little practical consequence. The only exception was removal of the composite access cover with the rod handle; females had a much higher heart rate than males (approximately 120 bpm on the average for females versus 107 bpm on the average for males).

4. Discussion

The major objective of this case study was to compare the physical stresses resulting from lifting the traditional steel access cover to those resulting from lifting the newer composite access cover. Comparison of physical stresses resulting from conventional lifting (lifting straight up) to physical stresses when removing the composite access cover with a rod handle was also of major interest. In order to evaluate the physical stresses imposed upon individuals during the removal of access covers and to compare the two products, the capacity of the individuals to lift an object similar to the size of access covers individually and in teams of two was determined. The isometric back strength and psychophysical lifting capacity of individuals and teams were therefore determined.

The results indicated that average isometric back strength and average psychophysical lifting capacity of individuals (MAWL) were far lower than the weight of the steel access cover (80.36 kg). Furthermore, even though the team isometric strengths were higher than the weight of the steel access cover, the team MAWLs of both males and females were substantially lower than its weight. If the steel access cover was lifted individually, its weight would result in a spinal compression of approximately 13210 N. The spinal compression tolerance data based on static conditions (Jäger and Luttmann, 1991) indicates that at this compression, all female and almost all male spines would be crushed. Even if the steel access cover is lifted by a team of two, the resulting spinal compression would exceed the spinal column compressive strength (static conditions) of almost all females and most males (96% of females and 63% of males). The steel access cover, thus, is clearly unsafe for manual handling. It should also be noted that even when the spinal compression forces exceeds 13210 N, there are some individuals who are able to lift loads that generate such high spinal compressive forces without any injury. This clearly suggests that under dynamic conditions the human spine can tolerate much larger compressive stresses than indicated by spinal tolerance for compressive forces from static loading. Thus, in order to determine the actual factor of safety spinal column tolerance for compressive forces under dynamic conditions should be known.

The composite access cover, which weighs 38.13 kg, can be removed in two ways: (1) by lifting it straight up (conventional way) individually or in a team and (2) by removing it with the help of the rod handle as shown in Fig. 1. As the results in Tables 3 and 4 indicate, this weight exceeds the psychophysical lifting capacity of most males and females. In fact, only 4 males out of 20 had an individual MAWL exceeding 38.13 kg. None of the female MAWLs exceeded or equaled 38.13 kg. The spinal compression when lifting the composite access cover alone, conventionally, would be approximately 5832 N. This again would exceed the spinal column strength (compressive; static loading conditions) of the majority of females and a large proportion of males (90% females and 52% of males).

Team lifting the composite access cover, however, would result in a spinal compressive force of only 2501 N (average 19.065 kg weight for each team member – in fact, the shorter members will lift slightly more than 19.065 kg and taller members slightly less than 19.065 kg). If spinal compression tolerance under static loading conditions is considered, this compressive force would result in a factor of safety of approximately 36% for females and 56% for males (based on average spinal column compressive strength data provided by Jäger and Luttmann, 1991). The factor of safety will be slightly lower for the shorter member of the team and slightly higher for the taller member of the team. Team lifting the composite access cover also resulted in lowest heart rates and RPE values.

While team lifting of composite access cover resulted in least stresses and was perceived least stressful by the individuals, practical considerations (no mechanical aid or team mate available) frequently may not allow it. In such situations, the access cover must be handled by only one individual, male or female. As the average individual MAWLs of males and females are well below 38.13 kg, lifting the composite access cover straight up is out of the question. Since removing the composite access cover with a rod handle, as opposed to lifting it, is feasible, the physical stresses resulting from using the proposed method need to evaluated. As mentioned earlier, a vertical force of approximately 21.34 kg needs to be exerted in order to remove the unseated composite access cover when using the rod handle. This force is slightly higher than the approximate weight each member of the team would lift when lifting the composite access cover in a team, conventionally (19.07 kg; shorter members of the team will lift more than 19.07 kg and taller members less than 19.07 kg). The spinal compressive force when the composite access cover is removed by the rod handle is approximately 2898 N. While this spinal compression is higher than the spinal compression for team lifting, it still provides a factor of safety (calculated from spinal compression tolerance under static loading conditions) of approximately 26% for females and 49% for males. Furthermore, even though the vertical force is higher than that encountered in team lifting the composite access cover, both males and females perceive access cover removal with the rod handle to be "light". Thus, removal of the composite access cover with the help of the rod handle individually or lifting it conventionally in a team of two are both acceptable methods.

5. Conclusions

The results of this study and the above discussion lead to the following conclusions:

(1) Teams isometric back strengths are significantly greater than individuals' isometirc back strength.

(2) Males, individually or in teams, have significantly greater isometric back strength than females.

(3) Males, individually or in teams, accept significantly heavier weights for lifting than females. Individually, on the average, males lifted 33.83 kg while females lifted 25.29 kg. Male teams lifted 76.04 kg compared to female teams, which lifted 59.56 kg. Shorter members of the team lifted approximately 6% to 8% more weight than taller members of the team.
(4) The weight of the steel access cover (80.36 kg) is substantially more than the average MAWL of either male or female teams.
(5) The steel access cover, if lifted conventionally, would impose spinal stresses (approximately 13210 N when lifting individually and 6186 N when lifting in teams) that would exceed the compressive strength of the spinal column (based on static loading conditions) of most individuals. Even if the steel access cover is lifted by a team of two members, the resulting spinal compressive stress would put the majority of the population at risk. The steel access cover, therefore, is unsafe for manual handling.
(6) The composite access cover can be lifted safely, conventionally, by a male or a female team of two or by males and females, individually, with the help of a rod handle.
(7) The use of a rod handle allows removal of the composite access cover by a single individual, male or female. The composite access cover, otherwise, would have to be lifted by a team of two individuals.
(8) The composite access cover and the recommended method of removing and replacing it (by a rod handle) not only significantly reduce the physical stress encountered in removing the access cover, they make it possible for an individual, male or female, to complete the task alone and safely.
(9) The individuals lifting the composite access cover, either conventionally or with the rod handle, have a factor of safety of at least 26% for females and 49% for males.

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