AN INVESTIGATION OF TEAM LIFTING USING PSYCHOPHYSICAL METHODS

by

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(ABSTRACT)

Lifting is one of the major causes of back injury in the workplace. Often, workers are
told to ask for the help of another worker when the load is too great to be lifted alone, yet the
effects of these team lifts have not been researched until recently. This experiment
investigated some of the variables which may affect the results of team lifting tasks.

The psychophysical methodology has been used for almost 30 years in trying to
determine the maximum acceptable weight of lift for industrial workers. Though two previous
studies of team lifting used the psychophysical approach, no effort was made to identify and
control variables which may affect team tasks. This experiment manipulated two variables,
box type (double or single) and isolation condition (curtains open or closed) to see whether these
would produce the psychosocial effects of social loafing and social facilitation. Three male
and three female two-person teams performed team lifts, using psychophysical methodology,
under all four conditions.

The only significant effect found was for gender. Female teams lifted 58.8% of the mass
the male teams lifted. Male teams lifted 92.5% and female teams 87.8% of the sum of their
individual lifts. This is in close agreement with other studies of team lifting. A regression
model was developed in order to predict the amount of weight a team can lift, with an $R^2$ of
0.962. The external validity of the task conditions was also investigated.
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# TABLE OF CONTENTS

ABSTRACT .......................................................................................................................... ii

ACKNOWLEDGMENTS ...................................................................................................... iii

LIST OF FIGURES ............................................................................................................. vii

LIST OF TABLES ............................................................................................................... viii

LIST OF APPENDICES .................................................................................................... ix

1. INTRODUCTION ......................................................................................................... 1

   1.1 RATIONALE .............................................................................................................. 1

       1.1.1 Psychophysics ................................................................................................. 2

       1.1.2 Social loafing and social facilitation ............................................................... 2

   1.2 RESEARCH OBJECTIVES ....................................................................................... 3

2. REVIEW OF THE LITERATURE ................................................................................. 5

   2.1 PSYCHOPHYSICS .................................................................................................... 5

   2.2 PSYCHOPHYSICS IN LIFTING ............................................................................. 6

   2.3 TEAM LIFTING ....................................................................................................... 9

       2.3.1 Studies of isometric, isokinetic, and isoinertial team lifting ......................... 9

       2.3.2 Studies of psychophysical team lifting ......................................................... 11

       2.3.3 Weakest member effect ................................................................................ 14

2.4 SOCIAL LOAFFING AND SOCIAL FACILITATION ............................................... 14

   2.4.1 The origins of social loafing theory ................................................................. 14

   2.4.2 The role of evaluation in social loafing and social facilitation ......................... 19

   2.4.3 Social loafing and social facilitation in relationship to team lifting ............... 21

   2.4.4 Redefining social loafing and social facilitation ............................................. 24
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5 VALIDITY</td>
<td>24</td>
</tr>
<tr>
<td>2.5.1 Statistical conclusion validity</td>
<td>25</td>
</tr>
<tr>
<td>2.5.2 Internal validity</td>
<td>26</td>
</tr>
<tr>
<td>2.5.3 Construct validity</td>
<td>26</td>
</tr>
<tr>
<td>2.5.4 External validity</td>
<td>29</td>
</tr>
<tr>
<td>3. EXPERIMENTAL METHOD</td>
<td>32</td>
</tr>
<tr>
<td>3.1 PARTICIPANTS</td>
<td>32</td>
</tr>
<tr>
<td>3.2 APPARATUS</td>
<td>39</td>
</tr>
<tr>
<td>3.3 EXPERIMENTAL DESIGN</td>
<td>46</td>
</tr>
<tr>
<td>3.3.1 Independent variables</td>
<td>46</td>
</tr>
<tr>
<td>3.3.2 Dependent variable</td>
<td>50</td>
</tr>
<tr>
<td>3.4 EXPERIMENTAL PROCEDURES</td>
<td>50</td>
</tr>
<tr>
<td>4. RESULTS</td>
<td>60</td>
</tr>
<tr>
<td>4.1 WEAKER VERSUS STRONGER TEAM MEMBER DIFFERENCES</td>
<td>60</td>
</tr>
<tr>
<td>4.2 MAXIMUM ACCEPTABLE WEIGHT OF LIFT</td>
<td>62</td>
</tr>
<tr>
<td>4.2.1 Gender</td>
<td>62</td>
</tr>
<tr>
<td>4.2.2 Box type</td>
<td>66</td>
</tr>
<tr>
<td>4.2.3 Curtain condition</td>
<td>66</td>
</tr>
<tr>
<td>4.2.4 Order</td>
<td>66</td>
</tr>
<tr>
<td>4.3 TESTS FOR SOCIAL LOAFING AND SOCIAL FACILITATION</td>
<td>67</td>
</tr>
<tr>
<td>4.3.1 Weaker member test</td>
<td>67</td>
</tr>
<tr>
<td>4.3.2 Stronger member test</td>
<td>69</td>
</tr>
<tr>
<td>4.3.3 Sum of individual MAWLs test</td>
<td>71</td>
</tr>
<tr>
<td>4.3.4 Degree of social loafing present</td>
<td>71</td>
</tr>
<tr>
<td>4.4 REGRESSION ANALYSIS</td>
<td>75</td>
</tr>
</tbody>
</table>
4.5 SUPPLEMENTAL DATA ANALYSIS ........................................ 79
  4.5.1 Team lifting questionnaire ....................................... 79
  4.5.2 Final questionnaire .............................................. 80
  4.5.3 Comments ......................................................... 83

5. DISCUSSION ..................................................................... 85
  5.1 SOCIAL LOAFING AND SOCIAL FACILITATION ................. 85
  5.2 WEAKEST MEMBER EFFECT ......................................... 87
  5.3 EXTERNAL VALIDITY .................................................. 88
  5.4 POSTURE AND VELOCITY DIFFERENCES ....................... 89

6. CONCLUSIONS .................................................................. 91
  6.1 CONCLUSIONS REGARDING THE HYPOTHESES ............... 91
  6.2 SOCIAL LOAFING AND SOCIAL FACILITATION ................ 92
  6.3 WEAKEST MEMBER EFFECT ......................................... 93
  6.4 EXTERNAL VALIDITY .................................................. 93
  6.5 GENERAL CONCLUSIONS ........................................... 94

7. TOPICS FOR FUTURE RESEARCH ...................................... 96

8. REFERENCES .................................................................... 98

APPENDICES ....................................................................... 103

VITA ............................................................................... 110
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Boxes used in the experiment</td>
<td>42</td>
</tr>
<tr>
<td>3.2</td>
<td>Benches used in the experiment</td>
<td>43</td>
</tr>
<tr>
<td>3.3</td>
<td>Whole body strength testing equipment configuration</td>
<td>45</td>
</tr>
<tr>
<td>3.4</td>
<td>Benches with large single box</td>
<td>56</td>
</tr>
<tr>
<td>3.5</td>
<td>Detail of large double box construction, showing false bottom, wooden spacers, and lead plate</td>
<td>57</td>
</tr>
<tr>
<td>3.6</td>
<td>Volunteer making adjustments during the isolation condition</td>
<td>58</td>
</tr>
<tr>
<td>3.7</td>
<td>Volunteers lifting the large single box</td>
<td>59</td>
</tr>
<tr>
<td>4.1</td>
<td>Team MAWL by Condition and Gender</td>
<td>64</td>
</tr>
</tbody>
</table>
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Summary of team lifting research to date</td>
<td>23</td>
</tr>
<tr>
<td>3.1</td>
<td>Female anthropometric dimensions measured in this experiment and in Karwowski and Pongpatanasuegsa (1988)</td>
<td>35</td>
</tr>
<tr>
<td>3.2</td>
<td>Male anthropometric dimensions measured in this experiment and in Karwowski and Mital (1986)</td>
<td>36</td>
</tr>
<tr>
<td>3.3</td>
<td>Female strength measurements in this experiment and in previous experiments</td>
<td>37</td>
</tr>
<tr>
<td>3.4</td>
<td>Male strength measurements in this experiment and in previous experiments</td>
<td>38</td>
</tr>
<tr>
<td>3.5</td>
<td>Experimental design</td>
<td>47</td>
</tr>
<tr>
<td>3.6</td>
<td>Balanced Latin Square design</td>
<td>48</td>
</tr>
<tr>
<td>4.1</td>
<td>Comparison of stronger and weaker team members mean strength measurements after teams were formed</td>
<td>61</td>
</tr>
<tr>
<td>4.2</td>
<td>Summary of results for the team MAWL (kg) of the sample population</td>
<td>63</td>
</tr>
<tr>
<td>4.3</td>
<td>ANOVA summary table of team MAWL results</td>
<td>65</td>
</tr>
<tr>
<td>4.4</td>
<td>Summary of weaker member effect t-tests</td>
<td>68</td>
</tr>
<tr>
<td>4.5</td>
<td>Summary of stronger member effect t-tests</td>
<td>70</td>
</tr>
<tr>
<td>4.6</td>
<td>Summary of the weaker plus stronger member MAWL t-tests</td>
<td>72</td>
</tr>
<tr>
<td>4.7</td>
<td>Percent of team MAWLs as compared to individual MAWLs (kg)</td>
<td>73</td>
</tr>
<tr>
<td>4.8</td>
<td>Individual contribution to team MAWL t-tests</td>
<td>76</td>
</tr>
<tr>
<td>4.9</td>
<td>Results of stepwise regression procedure</td>
<td>78</td>
</tr>
<tr>
<td>4.10</td>
<td>Summary of final team lifting questionnaire</td>
<td>82</td>
</tr>
</tbody>
</table>
LIST OF APPENDICES

Appendix A  Participant screening questionnaire................................. 103
Appendix B  Informed consent form......................................................... 104
Appendix C  Participant screening questionnaire...................................... 106
Appendix D  Team lifting experiment instructions..................................... 107
Appendix E  Team lifting questionnaire.................................................... 108
Appendix F  Final questionnaire............................................................... 109
1. INTRODUCTION

1.1 Rationale

Manual material handling accounts for many workplace injuries every year. According to the Bureau of Labor Statistics (1994), back injuries were responsible for 28% of all days away from work injuries in 1992, and 61% of these back injuries were caused by overexertion in lifting. This makes lifting an especially hazardous manual material handling task.

Often, when workers are being trained in safe lifting techniques, they are instructed to recruit a partner if the load is too heavy for one person to lift safely. However, workers are not usually trained in lifting techniques for lifts requiring more than one person. Until the mid-1980's there were not even any published reports of team lifting research or recommendations for team lifting limits. Objects that are lifted by teams in industry tend to be large, awkward, or heavy, all factors which make for a potentially more hazardous lift. Some examples of these types of loads are furniture, patients in health care settings, and large rolls of material which must be loaded onto machines. Most of the research and recommendations for individual lifting limits and techniques have addressed compact loads with handles, and usually refer only to lifts made in the sagittal plane; these characteristics are seldom found in team lifting situations. A desirable goal of manual material handling research is to establish guidelines for team lifting.
1.1.1 Psychophysics

One approach to the problem of manual material handling has been to study it from a psychophysical perspective. Psychophysics is the relationship of the perception of a sensation to the physical stimulus which produces the sensation. The method of magnitude production (using the method of adjustments) has been used to determine the maximum acceptable weight of lift for different lift conditions including lift height, box size, and frequency of lift. All of the literature on the validity of psychophysical methods has been in respect to tasks involving a single operator (Mital, 1983; Snook, 1983). Yet, two of the studies on team lifting have used psychophysical methods, without any consideration of the validity of using these methods for team activities (Karwowski, 1988; Johnson and Lewis, 1989). In using the psychophysical methodology for team lifting, researchers have been asking research participants to agree on their perception of a sensation. An analogy would be to ask two people to somehow adjust the brightness of a light until they both agreed that they could just perceive it.

1.1.2 Social loafing and social facilitation

There are also psychological variables that come into play whenever two or more people work together. These have not been very well addressed by the research on team lifting. The psychological concepts of social
facilitation and social loafing have undergone a recent surge of interest paralleling in time the research done on team lifting. Social loafing refers to the phenomenon which sometimes occurs when two or more people work together, and their team effort does not match the potential shown by team members working alone. For simple, well learned tasks such as lifting, this effect usually occurs when team members think their contributions to the team effort cannot be measured. Social facilitation is the name for the opposite effect, in which people working in teams out-produce the individual potentials of team members. This effect usually occurs when individual contributions to the team effort can be measured or separated.

1.2 Research Objectives

The validity of using psychophysical methods for tasks involving more than one person has not even been questioned in the research conducted to date. Also, the effects of psychosocial variables, such as those that contribute to social loafing and social facilitation, have not been tested in relation to team lifting. When trying to provide guidelines for safe lifting, it is better for any error to be in the conservative direction. For team lifting, we can assume that a conservative estimate of a team’s maximum acceptable weight of lift (MAWL) is twice the MAWL of the weaker team member based on
individual measurements of MAWL. This is a criterion level that seems to be the least likely to cause injury to the weaker team member.

This experiment attempted to test these hypotheses:

**Hypothesis 1:** When a psychophysical team lifting task is manipulated by changing box type and isolation condition, to enhance the effects of social loafing and social facilitation, there will be significant differences in the maximum acceptable weight of lift produced by the same team.

**Hypothesis 2:** One of the four experimental conditions (single or double large box with either an open or closed curtain) will produce a team MAWL which is twice the individual MAWL of the weaker team member.

**Hypothesis 3:** A multiple linear regression model can be developed which will accurately predict the amount of weight lifted during team lifts. The predictors for this regression model will be the whole body and grip strengths of team members, anthropometric measurements of team members, gender, and the individual MAWLs of team members.
2. REVIEW OF THE LITERATURE

2.1 Psychophysics

Psychophysics is the scientific study of the relation between stimulus and sensation (Gescheider, 1985). The psychophysical reference cited most often by early researchers into maximum acceptable weight of lift (MAWL) is a summary article by S. S. Stevens (1958). In this article, Stevens categorized the research that had been performed up to that time in the field of psychophysics. He distinguished three psychophysical parameters: the type of task the observer is to judge, the stimulus arrangement, and the statistical measure. He then categorized every psychophysical method based on these parameters and placed them according to what type of scale they produce (nominal, ordinal, interval, logarithmic interval, or ratio scale). The early researchers into the concept of a MAWL used Stevens’ paper to categorize the type of task as magnitude production, the stimulus arrangement as adjustable, and the statistical measure as a measure of central tendency. According to the Stevens paper, this method produces a ratio scale. Other researchers have used the typology of Gescheider (1985) to classify MAWL tasks as the method of adjustment, without regard to the type of scale being produced.
2.2 Psychophysics in lifting

The first use of psychophysics for the study of manual material handling tasks was presented by Snook and Irvine (1967). They used the classification of Stevens (1958) to label their technique as that of magnitude production (using the method of adjustment). The problem was viewed as magnitude production because the workers were asked to adjust the weight of a box to produce the MAWL that they could lift all day long at a given frequency without becoming unduly tired or fatigued. One of the major contributions of this paper was the description of a psychophysical protocol that could be used to investigate the effects of certain variables on lifting. Another major contribution was the division of lifting task variables into human variables (gender, age, training, and fitness of the worker) and task variables (size of object, height to and from which the object is lifted, and frequency of lift). This classification enabled Snook and Irvine and subsequent researchers to systematically manipulate these variables to determine their effect on the MAWL. Snook and various colleagues continued these studies for the next several years, culminating in a paper describing the results of seven experiments, and presenting tables of maximum acceptable weights of lift for various task and human variables (Snook, 1978).
Ayoub, Mital, Bakken, Asfour, and Bethea (1980) performed a comprehensive survey of all the research involving psychophysical methods of lifting, and combined the results into a table of maximum recommended weight of lifts. This table has as its parameters height of lift, gender of lifter, box dimension in the sagittal plane, and frequency of lift. The mean and standard deviation were given, so that the weights recommended for certain percentiles can easily be computed (assuming the data follows a normal distribution).

Mital (1983) attempted to verify the psychophysical approach in manual lifting. He did this by asking workers to estimate their MAWL in a 20-25 minute adjustment period, but then to continue lifting for 8 or 12 hours, and to continue adjusting the weight until the shift was over. The workers continued to adjust the weight downward over the entire shift, and so he concluded that the psychophysical method was not valid for manual lifting. (Mital used the term “verification” in the title, abstract, and methods section of this paper, but switched to the term “validate” in the introduction and concluding remarks, without any discussion of the meaning of either term).

In a later article, Mital (1984) concluded that the decrements in MAWL over 8 or 12 hours found in the 1983 study were fairly linear, and so the psychophysical method based on a 20-25 minute trial was valid, if the amount
of decrement was subtracted from the result (2% per hour worked for females and 3.5% per hour worked for males).

Snook (1983) did a thorough job of summarizing the advantages and disadvantages of psychophysics in studying manual handling tasks. The advantages were listed as:

1. Psychophysics permits the realistic simulation of industrial work.
2. Psychophysics can be used to study the very intermittent tasks that are commonly found in industry.
3. Psychophysical results are consistent with the industrial engineering concept of "a fair day's work for a fair day's pay."
4. Psychophysical results are very reproducible.
5. Psychophysical results appear to be related to low-back pain.

The disadvantages that Snook sees in psychophysics are:

1. Psychophysics is a subjective method that relies on self-report from subjects.
2. Psychophysical results from very fast frequency tasks are higher than recommended metabolic criteria.
3. Psychophysics does not appear sensitive to the bending and twisting motions that are often associated with the incidence of low-back pain.

These advantages and disadvantages will be seen to be important in discussing the application of psychophysical techniques to team lifting.
The most recent comprehensive study of psychophysical methods in manual material handling was performed by Ciriello, Snook, and Hughes (1993). Using the same protocols developed by Snook (1967), several new task variables were examined, including boxes without handles, carrying different box sizes, combination tasks, and lifting with extended horizontal reach. Tables were included which extended the body of data from which MAWLs for individual lifts can be determined for different populations.

2.3 Team lifting

2.3.1 Studies of isometric, isokinetic, and isoinertial team lifting

Karwowski and Mital (1986) published the first report on team lifting. They researched the additivity of maximum isometric and isokinetic strengths for teams of two and three males. Individual strengths were determined for 4 isometric and 2 isokinetic strength measures. Using modified handles, two- and three-man teams performed the same lifts that the individual subjects had performed. The results indicated that for isometric strengths, two-man strength was, on average, 94% of the sum of the individual strengths, and that three-man team strength was 90% of the sum of the individual strengths. Karwowski and Mital concluded that the lifting capacity of males in teamwork would be reduced as the number of team members increased. For the isometric lift, Karwowski and Mital used the
Caldwell Regimen (Chaffin, 1975). In this lifting procedure, a long or short bar attached to a single load cell is lifted, and individual effort cannot be evaluated, which will be important for interpreting the results in the context of social loafing. The isokinetic lifts tested dynamic lift strength and dynamic back extension strength, and the results for these dynamic tasks were lower than for the isometric tasks. On average, the strength of teams of two males was only 68% of the sum of their individual strengths, and three-man team strength was 58% of the sum of the individual strengths.

The same methods were used to study the additivity of maximum isometric and isokinetic strengths for females (Karwowski and Pongpatanasuegsa, 1988). The results for isometric strengths were similar to those for males, with a mean two-woman strength of 83% of the sum of individual strengths, and three-woman team strength of 84% of the sum of individual strengths. For the isokinetic lifts, the two-woman team strength was, on average, 68% of the sum of the individual strengths, and three-woman strength was 68.4% of the sum of individual strengths. In interpreting these results, Karwowski and Pongpatanasuegsa attributed the strength decrement to a phenomenon known as "social loafing"; this is the only time in any of the team lifting literature that either social loafing or social facilitation is referenced. Individual effort could not be measured in this study, as was also true in the Karwowski and Mital (1986) study.
Sharp, Rice, Nindl, and Williamson (1993a and 1993b) tested maximum dead-lift (isoinertial lift) capacity for 2-, 3-, and 4-person single- and mixed-gender teams. The subjects used specially modified weight-lifting bars for the team portion of the lift, and once again, the team lifts were significantly lower than the sum of the individual lifts. For two-person teams, all-male teams lifted 89.8% of the individual lifts, all-female teams lifted 91.9% of the sum of individual lifts, and mixed-gender teams lifted 79.7% of the sum of the individual lifts. Results were similar for the three- and four-person mixed- and single-gender teams. Individual effort was not identifiable under any of the conditions of this experiment, as weight was added to each arm of the frame after each successful lift, so that the weight remained balanced.

2.3.2 Studies of psychophysical team lifting

The first published report on team lifting using the psychophysical methodology was that of Karwowski (1988) who investigated maximum permissible load lifting capacity (maximum lifting capacity, teams or MLCT) for two-person teams of males and females. The MLCT was defined as the maximum load that subjects could lift in a single trial from floor to bench height. The terminology is different from that of MAWL, because the MAWL is applied to fairly high frequency lifting tasks, and the MLCT applies
to infrequent lifting (in this experiment, once every thirty minutes). The psychophysical methodology was used without apparent consideration of whether adding one or more persons to the task would invalidate use of these methods. Subjects adjusted the weight in a single large box after every lift, until they felt it corresponded to the maximum they could lift every 30 minutes. No details were given on the protocol for having the subjects adjust the weight (for example, whether they were allowed to discuss the weight, and whether they both made an adjustment every time). Karwowski found that teams of two males set an MLCT that was 87.5% of the sum of their individual maximum lifting capacities, and that teams of two females set an MLCT that was 91% of the sum of their individual maximum lifting capacities. This result could be explained by the theory of social loafing, since by using a single, large box, individual contributions to the lift could not be measured.

Johnson and Lewis (1989) had subjects perform a more traditional MAWL task. Subjects performed one- and two-person lift and lower tasks every thirty seconds for twenty minutes. For this experiment, a split box was used, and the subject had to ask the experimenter to adjust the weight in the box. Again, the validity of adding people to the task when using psychophysical techniques was not addressed. Using these methods, which were quite different from those of Karwowski, Johnson and Lewis found that
two-person teams of males could lift 30% more than the sum of their individual lifts. This finding contradicts the results found in every other team lifting experiment. The results of Johnson and Lewis can be explained by the theory of social facilitation, since by using a split box and having to ask the experimenter to adjust the weight, the team members knew that their individual contributions to the lift could be evaluated.

One important consideration for psychophysical studies of team lifting, given that these tasks are similar to real-life industrial tasks, is posture. For every study of maximum acceptable weight of lift for individuals, the lift posture is either specified or assumed to be in the sagittal plane. This type of posture is impossible for most team lifting tasks. If the box is to lifted and placed on a bench as in the Karwowski (1988) study, the team has to lift the box and then place it to the side of the lifters. Karwowski did not specify the posture, nor did he specify whether the same posture was used for the individual and team lifts. In the Johnson and Lewis (1989) study, the lifters lifted the box, held it for three seconds, and then lowered it to the floor. This eliminates the necessity of a sideways move to place the box, and allows the same posture to be used for both the individual and team lifts. However, this is not a realistic posture for team lifts occurring in industry. Seldom do workers simply lift something and then lower it again without moving it in some way.
2.3.3 Weakest member effect

In the Sharp, Rice, Nindl, and Williamson (1993b) study, the effect of the weakest team member on the team lift was considered for the first time. Sharp et al. found that for almost every combination of gender and team size, the team lift was almost exactly the same as the lift of the weakest member multiplied by the number of lifters. The weakest member effect could have contributed to all of the previous results for team-lifting, but this factor was not considered until the Sharp et al. (1993b) study. The finding of the weakest member effect lies behind the reasoning that the ideal team maximum acceptable weight of lift (MAWL) would be twice the MAWL of the weakest team member.

2.4 Social loafing and social facilitation

2.4.1 The origins of social loafing theory

There are two theories in the psychosocial literature which could explain the results obtained in team lifting research. "Social loafing" has been defined as the phenomenon which sometimes occurs when two or more people work together, and their team effort does not match the potential shown by team members working alone. "Social facilitation" is the name for
the opposite effect, in which people working in teams out-produce the individual potentials of team members.

Ingham, Levinger, Graves, and Peckham (1974) were the first modern researchers to investigate the effect that later became known as social loafing. They were interested in duplicating the research of Ringelmann, who in the late 19th century performed a rope pulling experiment, and found that as group size increased, the collective effort was inferior to the sum of the individual performances (Ingham et al., 1974). Ingham and colleagues first performed a pilot study to determine whether a performance decrement did indeed occur (it did). In the first experiment, Ingham and colleagues constructed an experimental apparatus to control for many variables that may have accounted for Ringelmann's results, since the reporting of Ringelmann’s work was second-hand and sketchy. (This has since been corrected with the publication of the Kravitz and Martin paper of 1986, in which the original Ringelmann article is summarized, and in which many previous misconceptions about Ringelmann and his experiments were cleared up.) The factors thought to have influenced Ringelmann’s results included subjects’ slippage while pulling, their angle of pulling, their effort in holding up the rope, and measurement accuracy. The apparatus controlled for all of these factors. Seventeen 6-member male teams were formed, and they performed several repetitions of a rope pulling task, in teams ranging in
size from 1 to 6 members (individual teams were broken down into various combinations of sub-teams). Significant performance decrements were reported for two- and three-person teams. Two-person teams pulled 9% less efficiently than a one-person team, and three-person teams performed 18% less efficiently than a one-person team.

Ingham and colleagues next hypothesized two possible sources for the decrement: loss of coordination as team size increased, and loss of motivation as team size increased. In the second experiment they controlled for coordination loss and allowed motivation to vary freely. Thirty-six subjects were assigned to six-member teams as before, but in each case the other five members of the team were experimenter confederates. Subjects were blindfolded and told that the effect of visual feedback on performance was being studied. Confederates were trained to give auditory and tactile feedback as though they were actually pulling the rope when in fact they were not. In each case the subject was pulling the rope alone, but in most of the conditions, the subject thought that he was pulling with from 1-5 other people. The performance decrements in this study were almost identical to those found in the first experiment, with a perceived three-person team decrement of 15% from when the subject knew he was pulling alone. There was no further significant decrement for four- to six-person teams, duplicating the results of the first study and indicating that motivation losses
may play a bigger role than coordination losses when teams are working together. Incidentally, Ringelmann's results were nearly identical to those of Ingham et al. for one- to three-person teams (Kravitz and Martin, 1986). He found a 7% decrement for two-person teams and a 15% decrement for three-person teams. However, Ringelmann reported further decrements for up to eight persons, but Ingham et al. did not find this trend in their study.

Latané, Williams, and Harkins (1979) coined the term "social loafing" to describe the effect found in their research on clapping and shouting in groups. Clapping and shouting were chosen because these tasks share some characteristics with rope pulling (all three tasks are maximizing, unitary, and additive, according to Steiner's (1972) typology). In their first experiment, Latané and colleagues had subjects shout and clap alone and in groups of two, four, and six. Subjects performed in full view and sight of each other and of the researchers. The resulting sound pressure was measured, and converted to dynes/cm², the physical unit of work involved in producing sound pressure. The results were similar to those of Ingham et al. and of Ringelmann. Two-person groups performed at 71% of the sum of their individual capacity, four-person groups at 51%, and six-person groups at 40%.

In order to determine how much of this decrement was due to coordination loss (which had been controlled for in the Ingham experiment) and how much was due to motivation loss (now termed social loafing),
Latané et al. devised a second experiment. Due to the nature of the task (this experiment used only a shouting task), they hypothesized that coordination losses would play a bigger role than in the rope pulling task, due to sound cancellation, directional coordination losses, and temporal coordination losses. In the second experiment, subjects were also assigned to groups of six. Subjects wore blindfolds and headsets and were told to shout as loud as they could, alone and in groups of two and six. In addition, there were trials in which the subject thought that he was performing in a group of two or six when he was in fact shouting alone (this condition was called pseudogroups). In addition, Latané et al. controlled for the numbers of observers watching each trial (this was held constant across trials). The hypothesis was that some of the results of the Ingham et al. experiment could be explained by the fact that the number of observers grew larger as the number of rope pullers grew smaller.

Under the conditions of the second experiment, subjects generally shouted louder than they had in the first experiment, possibly because they were less embarrassed while wearing blindfolds and headsets. Group output was still lower than the sum of individual capacity. Groups of two shouted at 66% of capacity, and groups of six shouted at 36% of capacity (compared to 71% and 40% from the first experiment). For the pseudogroups, subjects who believed there was one other person shouting with them performed at 82% of
capacity, and subjects who believed there were five others shouting with them performed at 74% of capacity. The difference between the actual and the pseudogroups was attributed to coordination loss, and the difference between the pseudogroups and the sum of individual capacity was attributed to social loafing. For this shouting experiment, each of these accounted for one half of the total loss. Latané et al. theorized three causes for social loafing: attribution and equity, submaximal goal setting, and lessened contingency between input and outcome. Later work would demonstrate that this third explanation, lessened contingency between input and outcome, may be the most important. Social loafing may occur proportionally to the participants’ feeling of being able to “hide in the crowd” and thus avoid evaluation.

2.4.2 The role of evaluation in social loafing and social facilitation

Harkins and Jackson (1985) explored the role of evaluation in social loafing. They hypothesized that the perceived pooling of effort in the earlier studies led to the findings of social loafing. Only when individual effort was identifiable did effort increase (the alone condition, when subjects knew they were acting alone). Harkins and Jackson noted that in all previous experiments, when the subjects knew they were performing alone and thus that their individual output was identifiable, they also knew that the other participants were performing the same task, and that their performance could
be directly compared or evaluated with those of other participants. Harkins and Jackson designed an experiment to separate the roles of identifiability and evaluation in producing social loafing. They had subjects brainstorm a number of uses for an object. There were two variables each at two levels, and subjects were assigned to one of the four conditions. One variable consisted of pooled versus identifiable outputs, and the other variable consisted of comparability versus no comparability. The results of this experiment suggest that the comparability was the major factor in determining whether social loafing would occur. Just knowing that their individual outputs were identifiable was not enough to prevent social loafing; subjects had to also feel that their output could be directly compared to the output of the other participants in order for the social loafing effect to disappear. Direct comparability is the concept that became known as evaluation in later studies.

The effect of evaluation on the phenomena of both social facilitation and social loafing was first shown by Harkins (1986). Up to this point, the two phenomena were thought to be separate. Social loafing is defined as the decrement in output by a group when the group works on the same task together, such as several people pulling on the same rope. (A performance decrement that occurs when the team effort is compared to the sum of individual efforts.) Social facilitation is defined as the improvement in group
performance when the group works on the same task, such as having a group of children standing next to each other winding fishing reels.

Harkins (1986) performed an extensive literature review of the many experiments in these two areas, and concluded that perhaps evaluation potential had a lot to do with the results. When people work on tasks as a group, whether together (as in pulling a rope) or separate (as in winding fishing reels), they tend to perform better if their individual effort can be evaluated, and worse if their individual effort cannot be separated.

Harkins ran two experiments to test his hypothesis. In the first, subjects were given a brainstorming task, and were then assigned to either a pairs or single condition, and another condition where they thought their individual performance could or could not be measured. Pairs outperformed singles, and the evaluation condition outperformed the no-evaluation condition. In the next experiment, subjects were given a vigilance task, and assigned to the same conditions as before. The results were the same as in the first experiment, validating this hypothesis for two fairly different types of tasks.

2.4.3 Social loafing and social facilitation in relationship to team lifting

Some of the early research in the areas of social loafing and social facilitation was performed with physical tasks, such as rope-pulling and reel
winding. Later attempts to replicate these early experiments showed that social loafing does occur in physical tasks, when the subject thinks that individual performance cannot be evaluated (Harkins, 1986). Social loafing and social facilitation effects could explain all of the results of the research to date on team lifting. In every study of team lifting but one, there was no potential to evaluate the contributions of individuals to the team lift. In each of these experiments, the team lift was less than the sum of the individual lifts (social loafing). In the one case (Johnson and Lewis, 1989), the individual contribution to the lift could be evaluated, and in this case, the team lift was greater than the sum of the individual lifts (social facilitation). The results of all the team lifting studies have been summarized and are presented in Table 2.1. Note that the Johnson and Lewis study stands out as a possible example of the social facilitation effect.

The effects of social loafing and social facilitation could explain all the results of team lifting research to date. However, to definitively prove that social loafing and social facilitation will occur with lifting tasks requires research in which the evaluation potential is manipulated. The experiment reported here attempted to manipulate task variables in a way that would produce the effects of social loafing and social facilitation, if these effects do indeed occur in lifting tasks.
<table>
<thead>
<tr>
<th>Study (year)</th>
<th>Type of lift, team gender</th>
<th>Team lift vs. individual</th>
<th>Evaluation possible</th>
<th>Weakest member effect investigated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Karwowski and Mital (1986)</td>
<td>Isometric Males</td>
<td>Decrease</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Karwowski and Pongpatanasuegsa (1988)</td>
<td>Isometric Females</td>
<td>Decrease</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Karwowski (1988)'</td>
<td>Dynamic lifting capacity M and F</td>
<td>Decrease</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Johnsen and Lewis (1989)'</td>
<td>Maximum acceptable lift Male</td>
<td>Increase</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Sharp et al. (1993 a and b)</td>
<td>Isoinertial lift M, F, mixed</td>
<td>Decrease</td>
<td>No</td>
<td>Yes, significant</td>
</tr>
</tbody>
</table>

1 These studies used psychophysical methodology.
2.4.4 Redefining social loafing and social facilitation

Social loafing and social facilitation have been defined in terms of team output, yet many of the studies in this area have designed experiments in such a way that people were performing alone, and only thought that they were performing in teams. In light of this, it might be more precise to define these phrases in terms of individual performance as well as team performance. Social loafing is a decrease in individual performance when one is or believes oneself to be a part of a team effort, as compared to when one knows that one is performing alone. Social facilitation is an increase in individual performance when one is or believes oneself to be a part of a team effort, as compared to when one knows that one is performing alone. This individual perspective will be useful in deciding whether social loafing and social facilitation do occur in team lifting tasks.

2.5 Validity

Some consideration of the meaning and types of validity will help in understanding whether or not any of the proposed experimental conditions are valid for determining team maximum acceptable weight of lifts (MAWLS). According to Cook and Campbell (1979), the validity of a test is concerned with the best available approximation to the truth of propositions. For Martin (1991), the validity of a measure consists of comparing it to some
standard agreed to be valid. If the measuring instrument agrees with the standard instrument, then the measure is a valid instrument. In any case, the first thing to decide is what is being measured. In the case of team MAWLs, we are trying to determine the maximum amount of weight that two or more people can lift for a certain amount of time under specified conditions. The question becomes: Is the psychophysical methodology a valid way of determining team MAWLs?

Cook and Campbell (1979) distinguish four types of validity and describe threats to each type. These are (1) statistical conclusion validity, (2) internal validity, (3) construct validity, and (4) external validity. All four validity types are important in this research, and will be addressed, but external validity is of greatest concern, and will be considered in depth.

2.5.1 Statistical conclusion validity

Cook and Campbell indirectly define “statistical conclusion validity” as freedom from drawing false inferences about covariation. The three questions to be asked in analyzing any experiment concern the statistical power of the experiment, whether the cause and effect covary, and if so, whether they covary to a significant degree. These questions are answered for this experiment using conventional statistical analyses which are described further in the Results section. For this experiment, the main statistical
question is whether the different lifting conditions result in significantly different maximum acceptable weight of lifts.

2.5.2 Internal validity

Once statistical conclusion validity is demonstrated, the next question is whether there is a causal relationship between the covariants, and if so, the direction of causality. Cook and Campbell (1979) refer to this as “internal validity.” For this team lifting experiment, the question of internal validity is whether the changes in conditions caused different team MAWLs, or whether they were caused by some other factor(s). Most of the threats to internal validity have been eliminated by using a balanced Latin Square design, and by having all team MAWLs determined in the same session. These procedures should eliminate fatigue, history, and maturation of participants as confounding factors.

2.5.3 Construct validity

Cook and Campbell (1979) refer to “construct validity” as the approximate validity with which generalizations can be made about higher order constructs, based on research operations. In this experiment, there are two constructs which were investigated. The first is whether the differences in team MAWLs under different research conditions are really attributable to
the higher order processes of social loafing and social facilitation. If the results of previous research into social loafing and social facilitation effects on physical work are valid, and if the research showing that evaluation potential is the major factor contributing to social loafing and social facilitation is valid, then the design of this experiment should be sufficient to demonstrate construct validity. If the manipulations intended to produce varying levels of evaluation potential also produce the expected changes in the team MAWLs, then the generalization could be made that team MAWLs are sensitive to social loafing and social facilitation manipulations.

The other construct which was investigated is that of the weaker member effect. This investigation attempted to determine if there are one or more treatment conditions which produce team MAWLs which are twice the individual MAWL of the weaker team member. Did the result occur because of the weaker member effect, or was it due to some other cause? The criterion already established as the ideal team MAWL is twice the MAWL of the weaker team member. This criterion itself seems to be valid (face validity, according to Anastasi, 1976) because individual MAWLs have been accepted as a valid method of determining the amount of weight a person can lift over a certain span of time under certain conditions. If individual MAWLs are valid, then a team MAWL of twice the MAWL of the weaker team member seems to be the only valid criterion for assuring that the maximum weight is
achieved without the risk of injury to the weaker team member. The
criterion itself was checked for construct validity by using a questionnaire at
the end of each team MAWL trial. If this weaker member criterion is valid,
then for any method that produces a team MAWL that matches the criterion,
the stronger team member should report that the ending weight is somewhat
less or a great deal less than they would be able to handle under the given
conditions. The weaker team member should report that the ending weight
is the same weight that they would be able to handle under the given
conditions. If two or more of the experimental conditions to be tested give
results that superficially meet the weaker member criterion, such a
questionnaire could be used to validate whether any of the results are really
due to the weaker member construct, or to some other cause.

One technique for determining construct validity is that of convergent
and divergent testing. The test score should correlate significantly with
variables it should correlate with and should not correlate significantly with
variables it should not correlate with. For team MAWLs, we might expect
high correlations with whole body strengths, grip strength, and gender, and
low correlations with age and handedness. This is based on the theory that if
we are measuring the same trait by the same method, with a different test,
and the scores are not correlated, then we are not measuring the same trait or
construct (Anastasi, 1976). If our construct is the ability of a team to establish

28
an MAWL which matches our criterion, and we use a psychophysical methodology to measure this, and the scores do not correlate well with each other, then the tests are measuring some other trait, such as susceptibility to social loafing and social facilitation effects.

2.5.4 External validity

The last type of validity considered by Cook and Campbell (1979) is "external validity." This involves being able to generalize the results of an experiment to and across populations, settings, and times. For this experiment, this is the most relevant type of validity. The main research question to be answered is whether it is valid to use psychophysical methods when performing team lifting research. The most basic argument against the use of these methods is that methods which were used and validated for single person tasks have been generalized to multi-person tasks without considering the validity of this generalization. Some of the variables that might impact a two person lifting task, but not a one person lifting task, are: how well the team members know one another; whether the team members can converse during the task; whether the team members can observe one another during the task; and whether there is to be evaluation potential for each member of the team, or whether the results will be pooled. These variables have not been addressed by past research on team lifting, yet
differences in methodology in regard to these variables can explain the conflicting results found in past research. The proposed experiment has been designed to take most of these variables into account. The conditions for team lifting that most closely approximate those of individual lifting are to have teammates who do not know one another and are not allowed to converse, who do not observe one another during the adjustment phase of the task, and who know that their individual efforts can be identified. The double box, closed curtain condition of this experiment meets most of these criteria, and if this condition produces a team MAWL which meets the weaker member criterion, then this methodology could be said to have external validity for psychophysical measurement of team lifting tasks (as generalized from single-person lifting tasks).

Another external validity concern is whether the task itself can be generalized to industrial environments. For a team lifting task, having the team lift industrial-type boxes at a consistent work pace would seem to be an appropriate test for determining the weight that a team could lift under the same conditions in a work environment. Some of the task conditions or methods will have more external validity than others for work environments. Conditions in which the experimenter and team members can evaluate the amount of the load that each participant is lifting is not a real world situation. The manipulations that will be necessary to produce
effects of social loafing and social facilitation will rob some of the test conditions of much of their external validity. Some of the experimental conditions will not be generalizable to real-world work environments, yet these might be the same conditions which would be the most similar to single person lifts. So even if one of the methods is found to have external validity as compared to individual MAWLs, the same method might not have external validity in regard to industrial environments. It could be that there will be no one method that will provide for both types of external validity. At the end of the experiment, all four experimental conditions were evaluated with regard to both types of external validity, using the questionnaire in Appendix F.
3. EXPERIMENTAL METHOD

3.1 Participants

Participants were 12 college students, six male and six female, who were formed into three two-person male teams and three two-person female teams. Participants were paid for their participation at the rate of $5.00 per hour. Originally there were to be 16 subjects, but after the initial screening and strength measurements, and the formation of teams, one of the female participants experienced an arm injury and had to withdraw before completing the team session, eliminating her team from further participation. One of the male teams was dropped from inclusion into the results after completion of the team task because they failed to follow instructions for determining the maximum acceptable weight of lift.

Participants were screened using the questionnaire in Appendix C to eliminate those who had experienced a previous back injury or who currently had any symptoms of back pain. Several of the participants had experienced some back pain in the last year, but none was severe, and none was currently experiencing back pain of any sort. The same questionnaire was also used to assess the participants’ manual material handling experience. Most of the studies which were used to develop tables of MAWLs used only experienced industrial workers, but both studies of team lifting using psychophysical methods employed inexperienced college students. The participants in this
experiment had a mean material handling experience of 22.2 months (s.d. = 24.2), including time spent in jobs such as food preparation, where material handling was part of the job requirements.

The participants were in good health generally, with 10 of the 12 participants reporting that they were in "good" physical condition, and two reporting that they were in "excellent" physical condition. None reported being in "fair" or "poor" physical condition. None of the twelve were currently taking any medication or drugs.

After filling out an informed consent form and the screening questionnaire, the participants were screened for standing wrist height. The experimental task began at 50th percentile wrist height for males and females, so participation was limited to those in the mid-50th percentile (25th to 75th percentile) in standing wrist height (all dimensions based on Webb Associates (1978) projected 1985 body size data). It was hoped that limiting participation in this way would minimize posture differences at the start of the team lift. Male standing wrist height was limited to a range of 84.5 to 89.7 cm, and female wrist height was limited to a range of 77.0 to 81.8 cm in order to be allowed to participate in the experiment (Webb Associates, 1978, projected 1985 body size data). In previous studies of team lifting, subjects were matched by stature to form teams, in order to eliminate differences that might occur due to different postures between team members. In this study, the
weakest member effect was investigated, so the teams were formed to emphasize weaker versus stronger team members, and stature matching was not possible.

Several anthropometric dimensions were recorded, for comparison to the Karwowski and Mital (1986) and Karwowski and Pongpatanasuegsa (1988) populations of team lifters. In these studies, several anthropometric dimensions were recorded for male and female participants, but there were some differences in the measurements taken in the two studies. Only those common to both studies were used in this experiment. The anthropometric characteristics of the sample population are given in Tables 3.1 and 3.2, along with values from previous studies for comparison purposes. Whole body strength and grip strength were also measured, as was individual MAWL. These measures were collected for use in constructing a regression model for team MAWL. The results of the strength measurements used in the experiment are listed in Tables 3.3 and 3.4. Included in this table are some values reported from subject populations from previous experiments, and these can be used for comparison to the subject population for this experiment. In most cases the anthropometric and strength measurements are in fairly close agreement with previous experiments, with the exception of maximum acceptable weight of lift, where the only previous study which used both males and females was that of Karwowski (1988). The lifts in that
Table 3.1 Female Anthropometric Dimensions Measured in this Experiment and in Karwowski and Pongpatanasuegsa (1988).

<table>
<thead>
<tr>
<th>Variable</th>
<th>This experiment</th>
<th>Karwowski and Pongpatanasuegsa (1988)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>s. d.</td>
</tr>
<tr>
<td>Age (years)</td>
<td>22.6</td>
<td>1.8</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>56.9</td>
<td>5.3</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>160.2</td>
<td>4.3</td>
</tr>
<tr>
<td>Acromial height (cm)</td>
<td>132.5</td>
<td>4.3</td>
</tr>
<tr>
<td>Chest circumference (cm)</td>
<td>90.9</td>
<td>5.4</td>
</tr>
<tr>
<td>Biceps flexed circumference (cm)</td>
<td>27.6</td>
<td>1.9</td>
</tr>
<tr>
<td>Variable</td>
<td>This experiment</td>
<td>Karwowski and Mital (1986)</td>
</tr>
<tr>
<td>--------------------------</td>
<td>-----------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td></td>
<td>n=6</td>
<td>n=6</td>
</tr>
<tr>
<td>Age (years)</td>
<td>21.5 2.6</td>
<td>24.0 1.7</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>81.2 25.9</td>
<td>79.7 19.4</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>177.0 3.3</td>
<td>180.0 6.7</td>
</tr>
<tr>
<td>Acromial height (cm)</td>
<td>146.5 4.1</td>
<td>149.6 6.4</td>
</tr>
<tr>
<td>Chest circumference (cm)</td>
<td>101.0 12.8</td>
<td>102.3 9.3</td>
</tr>
<tr>
<td>Biceps flexed circumference (cm)</td>
<td>34.6 5.2</td>
<td>34.7 3.5</td>
</tr>
</tbody>
</table>
Table 3.3 Female Strength Measurements in this Experiment and in Previous Experiments.

<table>
<thead>
<tr>
<th>Variable</th>
<th>This experiment n=6</th>
<th>Previous experiments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>s. d.</td>
</tr>
<tr>
<td>Grip strength (N)(^1)</td>
<td>262.8</td>
<td>49.2</td>
</tr>
<tr>
<td>Maximum acceptable weight of lift (kg)(^2)</td>
<td>11.68</td>
<td>3.2</td>
</tr>
<tr>
<td>Arm strength (N)(^3)</td>
<td>116.3</td>
<td>37.3</td>
</tr>
<tr>
<td>Leg strength (N)(^3)</td>
<td>285.7</td>
<td>87.3</td>
</tr>
<tr>
<td>Torso strength (N)(^3)</td>
<td>240.3</td>
<td>99.2</td>
</tr>
</tbody>
</table>

\(^1\)Karwowski and Pongpatalanaygsa (1988), n=8
\(^2\)From Karwowski (1988), n=6, represents maximum lifting capacity, once per 30 min., as opposed to this experiment, with lifts once per minute.
\(^3\)From Chaffin, Herrin, and Keyserling (1978), n=108
Table 3.4 Male Strength Measurements in this Experiment and in Previous Experiments.

<table>
<thead>
<tr>
<th>Variable</th>
<th>This experiment n=6</th>
<th>Previous experiments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>s. d.</td>
</tr>
<tr>
<td>Grip strength (N)$^1$</td>
<td>475.6</td>
<td>79.9</td>
</tr>
<tr>
<td>Maximum acceptable weight of lift (kg)$^2$</td>
<td>18.8</td>
<td>5.4</td>
</tr>
<tr>
<td>Arm strength (N)$^3$</td>
<td>321.0</td>
<td>89.7</td>
</tr>
<tr>
<td>Leg strength (N)$^3$</td>
<td>967.3</td>
<td>369.3</td>
</tr>
<tr>
<td>Torso strength (N)$^3$</td>
<td>650.3</td>
<td>199.4</td>
</tr>
</tbody>
</table>

$^1$ Karwowski and Mital (1986), n=6

$^2$ From Karwowski (1988), n=6, represents maximum lifting capacity, once per 30 min., as opposed to this experiment, with lifts once per minute.

$^3$ From Chaffin, Herrin, and Keyserling (1978), n=443
experiment were performed only once every thirty minutes, and so were much more representative of a truly maximal lift than the lifts used in this experiment. Karwowski’s female participants lifted approximately four times the amount that the females in this experiment lifted, and males lifted approximately three times the amount that males in this experiment lifted.

Sixteen research participants completed the first session, including informed consent, health screening questionnaire, wrist height screening, anthropometric and strength measurements, and determination of the individual maximum acceptable weight of lift. Four male and four female teams were formed after all sixteen participants had completed the first session. Teams were formed based on individual MAWL, with the strongest female paired with the fifth strongest female, the second strongest female paired with the sixth strongest female, and so forth. It was hoped that this would provide significantly stronger versus weaker team members so that the weaker member effect could be investigated.

3.2 Apparatus

The equipment consisted of several strength measurement devices, an anthropometer, a tape measure, a weight scale, two benches, one curtain and rod, ear muffs, lead plate and shot, and three “Snook boxes” (boxes with a
false bottom so that the lifters could not receive visual clues about the starting weight).

The first Snook box was a small single box for determination of individual MAWLs. The box was constructed of 2"x6" treated lumber and plywood. The dimensions of this box were 34x48x14 cm, similar to the box used by Snook (1967). Handles were on the 34 cm sides of the box, and the handles had a diameter of 4 cm, a length of 18 cm, and a clearance from the sides of the box of 3.7 cm. When empty, this single box had a mass of 8.3 kg. The second Snook box was a large single box, with dimensions of 68x48x14 cm, and with four handles on the sides of the box. This is basically the size of two single boxes adjoined, and was used for some of the team lifting conditions. This box had a mass of 15.4 kg. The third Snook box consisted of two of the small single boxes joined together so that they could be separated to determine the weight of each. Thus the dimensions of this box were also 68x48x14 cm. This box was called a large double box. Again, the four handles were on the sides of the box, in the same positions as in the large single box. This box had a mass of 16.6 kg when the two small boxes were connected. The false bottom was constructed of plywood. Under the false bottom were four small wooden spacers so that the false bottom was always raised above the real bottom by the same amount, whether or not there was any weight concealed under it. On top of the false bottom was a piece of black cloth for
containing the lead shot and making it easy to prepare for the next trial. After weighing the results of one trial, the cloth could be gathered up to collect all of the lead shot at once, so the false bottom could be lifted. This cloth was attached to the sides of the boxes with Velcro. These boxes are pictured in Figure 3.1.

The lead shot was scooped into and out of the box by the participants to adjust the weight of the box. The scoops were bird seed scoops purchased at a national hardware retailer. The lead plate was used to adjust the starting weight of the box to either a high or low starting weight in order to encourage the lifters to adjust the weight. The pieces of lead plate were concealed under the false bottom of the Snook boxes.

The participants lifted and lowered the boxes to and from the benches. The first bench was at the 50th percentile wrist height of 87.1 cm for males and 79.4 cm for females, measured from the floor to the middle of the box handle, based on Webb Associates projected 1985 body size (1978). The subjects lifted the boxes from this bench to another bench at the 50th percentile shoulder height of 146.1 cm for males and 132.4 cm for females, again measured from the floor to the middle of the box handle, and based on Webb Associates (1978). The layout of the benches is shown in Figure 3.2.

The curtain was an opaque white curtain suspended from the ceiling on a standard curtain rod using shower curtain hooks. There was a closed
Figure 3.1 Boxes used in the experiment.
Figure 3.2 Benches used in the experiment.
curtain condition and an open curtain condition. For the closed curtain condition, this curtain was drawn between the team members during the adjustment time so that they could not see how much weight the other person was adding or subtracting from the box. The ear muffs were also used during the closed curtain condition to muffle the sound of the lead shot being scooped into and out of the Snook boxes. The earmuffs were Bilsom Viking Model 2318C, with a noise reduction rating of 29.

Grip strength was measured using a Jamar grip dynamometer set at a grip span of 6.1 cm. Whole body strengths were measured using a University of Michigan Force Monitor System, consisting of two handle sets (long and short handle), a chain tether, floor anchor, load cell, and a personal computer for data collection. The dimensions for these devices were the same as those used by Chaffin, Herrin, and Keyserling (1978). The layout of this equipment is shown in Figure 3.3. The results of these strength tests were used as input predictors for the regression model.

A Detecto weight scale was used to measure body mass and final MAWLs to the nearest tenth of a kilogram. A GPM brand anthropometer was used to measure standing wrist height, height, and acromial height. Chest circumference and biceps flexed circumference were measured with the tape measure.
Figure 3.3 Whole body strength testing equipment configuration. From Chaffin, Herrin, and Keyserling (1978).
3.3 Experimental Design

The experimental design was a 2x2x2 mixed factors design, with two within-subjects variables and one between-subjects variable. There were three independent variables and one dependent variable. All teams were exposed to all four conditions, with order counter-balanced with a balanced Latin square design. The experimental design is shown in Table 3.5, and the balanced Latin square in Table 3.6. The Latin Square was designed with four teams of each gender in mind, so only three of the orders were used for each gender.

3.3.1 Independent variables

The only between-subjects independent variable was gender. Single gender teams were formed, and it was expected that the team MAWLs would be significantly higher for male teams than female teams. Also, it was expected that there might be significant between-gender differences in the responses to experimental conditions.

The within-subject independent variables were two task variables that were expected to encourage social loafing or social facilitation. These were manipulated and were chosen based on the evaluation potential they presented. The first of these variables was box type, large single or large double. With the large double box, the boxes could be separated and weighed
<table>
<thead>
<tr>
<th>C</th>
<th>Single</th>
<th></th>
<th>Double</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
</tr>
<tr>
<td>U</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>Open</td>
<td>MT2\textsuperscript{2}</td>
<td>FT2\textsuperscript{3}</td>
</tr>
<tr>
<td>T</td>
<td></td>
<td>MT3</td>
<td>FT3</td>
</tr>
<tr>
<td>A</td>
<td></td>
<td>MT4</td>
<td>FT4</td>
</tr>
<tr>
<td>I</td>
<td>Closed</td>
<td>MT2</td>
<td>FT2</td>
</tr>
<tr>
<td>N</td>
<td></td>
<td>MT3</td>
<td>FT3</td>
</tr>
<tr>
<td>S</td>
<td></td>
<td>MT4</td>
<td>FT4</td>
</tr>
</tbody>
</table>

\textsuperscript{1} Male team 1 was dropped from the experiment, and female team 1 dropped out of the experiment.
\textsuperscript{2} MT = Male team
\textsuperscript{3} FT = Female team
<table>
<thead>
<tr>
<th></th>
<th>Team 1</th>
<th>Team 2</th>
<th>Team 3</th>
<th>Team 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Treatment</strong></td>
<td>SB, OC²</td>
<td>SB, CC</td>
<td>DB, OC</td>
<td>DB, CC</td>
</tr>
<tr>
<td><strong>Order</strong></td>
<td>SB, CC</td>
<td>DB, OC</td>
<td>DB, CC</td>
<td>SB, OC</td>
</tr>
<tr>
<td>(for male</td>
<td>DB, CC</td>
<td>SB, OC</td>
<td>SB, CC</td>
<td>DB, OC</td>
</tr>
<tr>
<td>teams)</td>
<td>DB, OC</td>
<td>DB, CC</td>
<td>SB, OC</td>
<td>SB, CC</td>
</tr>
</tbody>
</table>

¹ This was the original design. After male team 1 was dropped from the study, the first order was not used for male teams. For female teams, the order was reversed, so after female team 1 dropped out of the experiment, the fourth order was not used for female teams.

²SB = Large Single Box          DB = Large Double Box
OC = Open Curtain              CC = Closed Curtain
after each team MAWL was selected. Thus, the team members knew that their individual contribution to the lift could be measured. With the large single box, individual evaluation was not possible. The second within-subject independent variable was curtain condition, open or closed. During the open curtain condition, each team member was able to see how much weight the other team member was adding or subtracting, and thus there was some level of evaluation potential possible. When the curtain was closed, the team members had less information about how much weight the other person was adding or subtracting (the earmuffs helped mask auditory clues). The single box, closed curtain condition was expected to produce the lowest evaluation potential, the largest social loafing effect, and the lowest team MAWLs. The double box, open curtain condition was expected to produce the highest evaluation potential, the largest social facilitation effect, and the highest team MAWLs. The other two conditions were expected to produce intermediate MAWLs which were somewhat similar to each other, although the large double box, in which each box was weighed, was expected to produce a somewhat higher team MAWL than the large single box.
3.3.2 Dependent variable

The dependent variable was the team MAWL, which was defined as the average of the MAWL obtained with a heavy starting weight and the MAWL obtained with a light starting weight for each condition.

3.4 Experimental Procedure

Participants were recruited from among university students using posters. Those who responded were scheduled to come in and were given the general description of the experiment to read (Appendix A). Those who agreed to participate after reading the general description were given the informed consent form to read and sign (Appendix B). At this point, participants were screened for risk of injury using the health screening questionnaire in Appendix C. Any participants who reported back pain in the last year or last three months were questioned further as to the degree of pain, and whether they were currently experiencing back pain. Those who had experienced no more than minor muscle soreness in the past three months, were not currently experiencing any back pain, and had no chronic back problems were accepted as participants in the experiment. Next, anthropometric measurements and grip strengths were determined for each participant, beginning with standing wrist height. Those whose standing wrist heights fell outside of the 25th to 75th percentile range were screened
out based on these measurements. Finally, three whole body strength measurements were obtained for each participant.

After the anthropometric and strength measurements were obtained, the maximum acceptable weight of lift was determined for each participant. The method pioneered by Snook (1967) was followed for this MAWL determination. The participants lifted and lowered the small single box, which contained either a heavy or light starting weight (concealed by the false bottom). This was to encourage the participants to make adjustments to the starting weight. They continued to lift and lower the weight from wrist to shoulder height at one minute intervals for 20 minutes, adjusting the weight as often as needed. Instructions are presented in Appendix D, and were audiotaped to provide consistency of instruction across participants. The basic instructions for the task were as follows: “You are to imagine that you are being paid for the amount that you are able to lift in 8 hours, at a frequency of once per minute, without becoming fatigued or out of breath. After each lift and lower, you may adjust the weight in the box upward or downward in order to meet this criterion, using the lead shot and scoop provided. At these levels of weight, you must make a fairly significant adjustment in order to be able to detect a difference in the adjusted weight. At the end of 20 minutes, the trial will end and the final weight will be recorded. You will then perform another trial, and the average of the two trials will determine your
maximum acceptable weight of lift." Complete instructions are found in Appendix D. Frequency of lift was the same as for the team lifting conditions, once per minute.

The lift was paced by an audiotape, which instructed the participants to "Ready . . . Set . . . Lift . . . Release . . . And lower . . . Make adjustments if needed" once every minute. After twenty minutes, the final weight was recorded, and after a ten minute rest, the subject performed the same task, with a different starting weight (concealed by the false bottom). If the two final weights were within 15% of each other, the final weights were averaged, and this was the individual MAWL for that person. If the weights were not within 15% of each other, another trial was run, with an alternating heavy or light starting weight, to see if a third trial resulted in two consecutive final weights which were within 15% of each other. If the third trial also resulted in two consecutive weights which were not within 15% of each other, that participant was dropped from the experiment. Only one participant was rejected for this reason. The screening, measurements, and determination of individual MAWLs took one and one-half hours per subject, or two hours when a third MAWL trial was necessary. This completed the first of two sessions.

The starting weights for the individual MAWL trials were based on Snook's (1978) tables of maximum acceptable weights of lift and lower. These
were taken from Snook's tables, with the following assumptions: 36 cm box width (as opposed to 34 cm for this experiment), travel distance of 51 cm (as opposed to 59 cm for the males and 53 cm for the females for this experiment), knuckle height to shoulder height lift (as opposed to wrist height to shoulder height), and one lift per minute (the same as this experiment). Based on these assumptions, starting weights were chosen which are the recommended weights for the 10th and 90th percentile of the population. For males, the light starting weight was 16 kg for the individual MAWL and the heavy starting weight was 36 kg for the individual MAWL. For females, the light starting weight was 11 kg and the heavy starting weight was 19 kg. It was obvious from running the individual MAWL trials that these weights were somewhat high, possibly because the lift was asymmetrical, and because several of the lifters were inexperienced in manual material handling. For the team lift, the starting weights were adjusted downward based on the mean individual MAWL of the weaker and stronger team members. This tailored the starting weights to the sample population. For males, this process resulted in a light team starting weight of 30 kg and a heavy weight of 52 kg. For females, the light starting weight for teams was 20.4 kg and the heavy starting weight was 30.4 kg. Heavy or light starting weights were randomly assigned, with half of the trials starting with a heavy weight, and half starting with a light weight. Each of the four
experimental conditions had both a heavy starting weight trial and a light starting weight trial.

After all of the individual MAWLs were determined, four male teams and four female teams were formed. The teams were formed by matching the male with the highest MAWL with the male with the fifth highest MAWL, then the male with the second highest MAWL with the male with the sixth highest MAWL, and so forth. This was to ensure that there was a defined weaker team member for every team. Females were matched using the same procedure.

After the teams were formed, they were scheduled to come in for the second of two sessions. Each team was exposed to all four team conditions on the same day. For each condition, each team member adjusted the weight on his or her side of the box without discussing the adjustment, although the teammates could discuss issues other than the task. For the closed curtain conditions, the curtain was drawn and earmuffs were donned after each lift, so that adjustments could be made in privacy, but the curtain was opened again before the next lift so that the visual clues necessary for safe team lifting were present. All other task conditions and data collection procedures were the same as for the individually determined MAWLs, except that immediately after each team MAWL trial was completed, a questionnaire was filled out by each team member in order to help validate the weakest member
criterion discussed previously. This questionnaire appears in Appendix E.

Each team session took four hours. Participants were paid after each session, and were given a $5.00 bonus for returning and completing the second session for a total payment of $35. Photographs of the experimental task are shown in Figures 3.4 through 3.7.
Figure 3.4 Benches with large single box.
Figure 3.5 Detail of large double box construction, showing false bottom, wooden spacers, and lead plate.
Figure 3.6 Volunteer making adjustments during the isolation condition (this volunteer did not participate in the experiment).
Figure 3.7 Volunteers lifting the large single box (these volunteers did not participate in the experiment).
4. RESULTS

4.1 Weaker versus stronger team member differences

In order to investigate whether matching the teams in the manner previously described really did provide significantly stronger and weaker team members, two-sample t-tests assuming equal variance were run. For females, the individual MAWL of the stronger team member was significantly higher than the MAWL of the weaker team member \( (p = 0.036) \). On every other strength measurement for females, there was no significant difference between the results obtained for the weaker and stronger team members. For males, the individual MAWL of the stronger team member was significantly higher than the MAWL of the weaker team member \( (p = 0.015) \). Torso strength was also significantly higher for the stronger team member for males \( (p = 0.018) \). For every other strength measurement for males (grip, arm, and leg strength), the difference between the weaker and stronger member was not significant. Comparisons between weaker and stronger team member strength measurements are found in Table 4.1. Since one female team dropped out of the experiment after the teams were formed, and since the results of one male team were dropped from consideration as described earlier, these t-tests were performed based on three teams of each gender.
Table 4.1 Comparison of Stronger and Weaker Team Members Mean Strength Measurements after Teams Were Formed.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Male</th>
<th></th>
<th></th>
<th>Female</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weaker</td>
<td>Stronger</td>
<td>P-value</td>
<td>Weaker</td>
<td>Stronger</td>
<td>P-value</td>
<td></td>
</tr>
<tr>
<td>MAWL (kg)</td>
<td>*14.35</td>
<td>*23.17</td>
<td>0.015</td>
<td>*9.45</td>
<td>*13.82</td>
<td>0.036</td>
<td></td>
</tr>
<tr>
<td>Grip (N)</td>
<td>425.0</td>
<td>526.3</td>
<td>0.125</td>
<td>261.5</td>
<td>274.1</td>
<td>0.768</td>
<td></td>
</tr>
<tr>
<td>Arm (N)</td>
<td>282.0</td>
<td>359.9</td>
<td>0.341</td>
<td>175.1</td>
<td>111.2</td>
<td>0.463</td>
<td></td>
</tr>
<tr>
<td>Leg (N)</td>
<td>731.1</td>
<td>1203.5</td>
<td>0.121</td>
<td>367.2</td>
<td>279.9</td>
<td>0.440</td>
<td></td>
</tr>
<tr>
<td>Torso (N)</td>
<td>*488.7</td>
<td>*811.8</td>
<td>0.018</td>
<td>250.3</td>
<td>239.6</td>
<td>0.902</td>
<td></td>
</tr>
</tbody>
</table>

* denotes significance at p<0.05.
4.2 Maximum acceptable weight of lift

The team maximum acceptable weight of lifts (MAWLs) are summarized in Table 4.2. The MAWL data collected for each condition and gender was subjected to an analysis of variance (ANOVA) using the SuperANOVA software. The ANOVA table is shown in Table 4.3. The only significant effect was gender (p=0.014). Box type and curtain condition had no significant effect on the amount of mass the teams lifted. These results are presented graphically in Figure 4.1.

4.2.1 Gender

Over all conditions, males had a team MAWL of 34.7 kg, while females had a team MAWL of 20.42 kg. This difference was significant at p = 0.0142. Female teams lifted 59% of the mass the male teams lifted, as compared to the 73% ratio reported in Karwowski's (1988) study. Karwowski's task involved lifting a load from the floor to a bench at about hip height, while the task for this experiment involved lifting a load from wrist height to shoulder height. Chaffin et al. (1978) reported an arm strength for females of 52.3% of that for males. The difference in task may account for the gender difference in the results of this study and that of Karwowski.
<table>
<thead>
<tr>
<th>Condition</th>
<th>Females</th>
<th></th>
<th></th>
<th>Males</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>s.d.</td>
<td>Mean</td>
<td>s.d.</td>
<td></td>
</tr>
<tr>
<td>Single box, closed curtain</td>
<td>20.67</td>
<td>1.20</td>
<td>35.60</td>
<td>6.39</td>
<td></td>
</tr>
<tr>
<td>Single box, open curtain</td>
<td>19.25</td>
<td>3.52</td>
<td>33.32</td>
<td>7.24</td>
<td></td>
</tr>
<tr>
<td>Double box, closed curtain</td>
<td>20.83</td>
<td>3.16</td>
<td>34.97</td>
<td>5.66</td>
<td></td>
</tr>
<tr>
<td>Double box, open curtain</td>
<td>20.92</td>
<td>2.50</td>
<td>35.55</td>
<td>3.16</td>
<td></td>
</tr>
</tbody>
</table>
Figure 4.1 Team MAWL by Condition and Gender. Points with the same letters are not significantly different at p<0.05.
<table>
<thead>
<tr>
<th>Effect</th>
<th>df</th>
<th>Sum of Squares</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>* Gender (G)</td>
<td>1</td>
<td>1251.37</td>
<td>17.28</td>
<td>0.014</td>
</tr>
<tr>
<td>Teams/G</td>
<td>4</td>
<td>289.66</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Box Type (BT)</td>
<td>1</td>
<td>4.42</td>
<td>1.06</td>
<td>0.361</td>
</tr>
<tr>
<td>BT x G</td>
<td>1</td>
<td>0.02</td>
<td>0.005</td>
<td>0.948</td>
</tr>
<tr>
<td>BT x Teams/G</td>
<td>4</td>
<td>16.62</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Curtain Condition (CC)</td>
<td>1</td>
<td>3.45</td>
<td>1.093</td>
<td>0.355</td>
</tr>
<tr>
<td>CC x G</td>
<td>1</td>
<td>0.05</td>
<td>0.02</td>
<td>0.906</td>
</tr>
<tr>
<td>CC x Teams/G</td>
<td>4</td>
<td>12.63</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BT x CC</td>
<td>1</td>
<td>7.15</td>
<td>2.41</td>
<td>0.195</td>
</tr>
<tr>
<td>BT x CC x G</td>
<td>1</td>
<td>0.070</td>
<td>0.24</td>
<td>0.652</td>
</tr>
<tr>
<td>BT x CC x Teams/G</td>
<td>4</td>
<td>11.85</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* denotes significance at p<0.05
4.2.2 Box type

There was no significant effect for box type. For females, the single box condition produced a mean team MAWL of 19.96 kg, and the double box condition produced a mean team MAWL of 20.86 kg. For males, the mean team MAWLs were 34.46 kg for the single box condition, and 35.26 for the double box condition.

4.2.3 Curtain condition

The condition of the curtain and the use of earmuffs during the adjustment period had no significant effect on the team MAWL. For females, the mean team MAWLs were 20.08 kg for the open curtain condition, and 20.75 for the closed curtain condition. For males, the mean team MAWLs were 34.43 kg for the open curtain condition, and 35.28 kg for the closed curtain condition.

4.2.4 Order

Since the experimental session took four hours, an ANOVA was conducted to test for the effect of order on the team MAWL. This test showed no significant effect for order (p>0.05). If there had been a significant order effect, and post hoc analysis had shown that the fourth condition produced a significantly lower MAWL than the first condition, then the order effect
would have been considered a result of fatigue. In this case, the data would have been adjusted for fatigue, using the factors reported by Mital (1984). The mean team MAWL did decrease over each order, but only from 28.59 kg in the first trial to 27.08 in the fourth trial. Male and female teams were also tested separately for an order effect, and order was not significant for either gender (p>0.05).

4.3 Tests for social loafing and social facilitation

4.3.1 Weaker member test

For each condition and for both genders, the individual MAWL of the weaker team member was doubled and compared to team MAWL using a two-sample t-test assuming equal variance. For female teams, none of the four conditions produced team MAWLs which were significantly different from the doubled weaker member MAWL. For male teams also, none of the conditions produced significant differences between the team MAWL and the doubled weaker member MAWL. Finally, the male and female data were combined, and again, there were no significant differences. For both genders, every condition produced team MAWLs which were not significantly different from the doubled MAWL of the weaker team member. Based on these results, a weaker member effect cannot be ruled out. Table 4.4 summarizes the weaker member effect t-tests by gender.
Table 4.4 Summary of the Weaker Member Effect t-tests.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Male 2x Weaker</th>
<th>Male Team</th>
<th>Female 2x Weaker</th>
<th>Female Team</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SB, CC</td>
<td>28.70</td>
<td>35.60</td>
<td>18.90</td>
<td>20.67</td>
<td>0.459</td>
</tr>
<tr>
<td>SB, OC</td>
<td>28.70</td>
<td>33.32</td>
<td>18.90</td>
<td>19.25</td>
<td>0.909</td>
</tr>
<tr>
<td>DB, CC</td>
<td>28.70</td>
<td>34.33</td>
<td>18.90</td>
<td>20.83</td>
<td>0.519</td>
</tr>
<tr>
<td>DB, OC</td>
<td>28.70</td>
<td>35.55</td>
<td>18.90</td>
<td>20.92</td>
<td>0.456</td>
</tr>
</tbody>
</table>

Note: All comparisons lack significance at p<0.05 using a two-tailed, two-sample t-test assuming equal variance.
4.3.2 Stronger member test

The individual MAWL of the stronger team member was doubled and compared to the team MAWL using t-tests, as was done with the weaker member MAWL. For females, there were significant differences for three of four conditions (p<0.05). The double box, closed curtain condition did not produce a team MAWL that was significantly different from the doubled MAWL of the stronger member. For males, two of the conditions produced team MAWLs which were significantly different from the doubled MAWL of the stronger member (p<0.05). The two conditions which did not produce significance were the single box, closed curtain and the single box, open curtain. When the male and female data were pooled, none of the conditions produced significant differences (p>0.05). These results are summarized in Table 4.5. For females, there does not appear to be a stronger member effect for the team MAWL, but for males, it cannot be ruled out, since there was a lack of significance in two of the conditions. Note that all p-values were close to significance, and with a more powerful experimental design, the stronger member effect might have been able to be ruled out.
| Condition | Male | | | Female | | | | |
|-----------|------|------|------|------|------|------|------|
|           | 2x Stronger | Team | P-value | 2x Stronger | Team | P-value |
| SB, CC    | 46.33 | 35.60 | *0.068 | 27.63 | 20.67 | 0.027 |
| SB, OC    | 46.33 | 33.32 | *0.052 | 27.63 | 19.25 | 0.040 |
| DB, CC    | 46.33 | 34.33 | 0.030 | 27.63 | 20.83 | *0.062 |
| DB, OC    | 46.33 | 35.55 | 0.021 | 27.63 | 20.92 | 0.049 |

Note: * denotes comparisons which lack significance at p<0.05 using a two-tailed, two-sample t-test assuming equal variance.
4.3.3 Sum of individual MAWLs test

Another t-test was run to compare the sum of the individual MAWLs (weaker member MAWL + stronger member MAWL) to the team MAWL. For both males, females, and pooled data, none of these comparisons were significantly different ($p>0.05$). The presence of a sum of individual MAWLs effect cannot be discounted as a contributing factor to the team MAWL. The results of these t-tests are summarized in Table 4.6.

4.3.4 Degree of social loafing present

Using a team based definition, there was no social facilitation produced by any of the conditions, i.e., under no condition did the team MAWL exceed the sum of the individual MAWLs. For females over all conditions, the team MAWL was 87.75% of the sum of the individual MAWLs. For males over all conditions, the team MAWL was 92.49% of the sum of the individual MAWLs. The male and female results were subjected to a t-test to determine whether this difference was significant, and it was not ($p>0.05$). The results for males and females were pooled, and over all conditions the team MAWL was 90.68% of the sum of the individual MAWLs. These results are summarized in Table 4.7. Karwowski (1988) found that a team of two females lifted 91.0% of the sum of their individual lifts and teams of two males lifted 87.5% of the sum of their individual lifts. These figures are in close
<table>
<thead>
<tr>
<th>Condition</th>
<th>Male</th>
<th></th>
<th></th>
<th>Female</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sum of MAWLs</td>
<td>Team MAWL</td>
<td>P-value</td>
<td>Sum of MAWLs</td>
<td>Team MAWL</td>
<td>P-value</td>
</tr>
<tr>
<td>SB, CC</td>
<td>37.52</td>
<td>35.60</td>
<td>0.706</td>
<td>23.27</td>
<td>20.67</td>
<td>0.274</td>
</tr>
<tr>
<td>SB, OC</td>
<td>37.52</td>
<td>33.32</td>
<td>0.459</td>
<td>23.27</td>
<td>19.25</td>
<td>0.226</td>
</tr>
<tr>
<td>DB, CC</td>
<td>37.52</td>
<td>34.33</td>
<td>0.482</td>
<td>23.27</td>
<td>20.83</td>
<td>0.412</td>
</tr>
<tr>
<td>DB, OC</td>
<td>37.52</td>
<td>35.55</td>
<td>0.602</td>
<td>23.27</td>
<td>20.92</td>
<td>0.385</td>
</tr>
</tbody>
</table>

Note: All comparisons lack significance at p<0.05 using a two-tailed, two-sample t-test assuming equal variance.
| Condition | Female | | | Male | | |
|---|---|---|---|---|---|
| | Sum of Ind. MAWLs | Team MAWL | Decrement (% of sum) | Sum of Ind. MAWLs | Team MAWL | Decrement (% of sum) |
| Single, closed | 23.27 | 20.67 | -12.58% | 37.52 | 35.60 | -5.38% |
| Single, open | 23.27 | 19.25 | -20.87% | 37.52 | 33.32 | -12.61% |
| Double, closed | 23.27 | 20.83 | -11.68% | 37.52 | 34.33 | -9.27% |
| Double, open | 23.27 | 20.92 | -11.24% | 37.52 | 35.55 | -5.53% |
| All conditions | 23.27 | 20.42 | -13.96% | 37.52 | 34.70 | -8.12% |

Note: None of these differences are significant, as presented in Table 4.6.
agreement with the results found here. The t-test which compared the sum of the weaker and stronger individual MAWL to the team MAWL showed no significance, so although the results are very comparable to other team-lifting results, the level of social loafing found in this experiment was not significant.

Differences based on the individual definitions of social loafing and social facilitation were also tested. Given that the team MAWL was higher than the doubled MAWL of the weaker member, and lower than the doubled MAWL of the stronger member, it might be that the stronger member is being forced to loaf, and the weaker member to facilitate. For the double box conditions, the boxes were separated and weighed individually after completion of the team lift. These measurements were attributed to the weaker or stronger team member. The results for both double box conditions were combined. For females, the mean individual MAWL of the weaker member was 9.45 kg, and the mean individual effort of the weaker member under team conditions was 10.17 kg. This might indicate that social facilitation is being forced on the weaker female team member, but a two-sample t-test assuming equal variance failed to show significance. For the stronger female team members, the mean individual MAWL was 13.82 kg, and the individual effort under team conditions was 10.71 kg. Again, this difference was not significant. Males showed the same trends (the weaker
members lifted more under the team condition than the individual condition, and the stronger member lifted less), but none of the results were significant. Male and female data combined also failed to show significance. The results of these tests are shown in Table 4.8.

4.4 Regression analysis

For the regression analyses, the data for all four conditions were pooled, for two reasons. First, the analysis of variance had not shown any significant effect for conditions. Second, since a large number of regressors were used, and there were relatively few data points, pooling the conditions allowed for a more robust regression model. With six teams and four conditions there were 24 data points for the regression analysis.

The first regression analysis used the 24 data points for team MAWLs and 11 predictors to model team MAWL as a function of strength measurements. The regressors were team gender, and the grip, arm, leg, and torso strengths of the weaker and stronger team members, as well as the individual MAWL of the weaker and stronger team members. The analysis was run using Minitab software, using the stepwise regression procedure. This procedure checked each predictor to see which produced the best linear regression. Once the best linear regression was found, then all of the two predictor models which included the first predictor were tested, to see which
Table 4.8 Tests for Differences in the Individual Contribution to the Team MAWL.

<table>
<thead>
<tr>
<th>Member</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MAWL</td>
<td>MAWL</td>
</tr>
<tr>
<td></td>
<td>P-value</td>
<td>P-value</td>
</tr>
<tr>
<td>Weaker</td>
<td>14.35</td>
<td>15.03</td>
</tr>
<tr>
<td>Stronger</td>
<td>23.17</td>
<td>19.91</td>
</tr>
</tbody>
</table>

Note: All comparisons lack significance at p<0.05 using a two-tailed, two-sample t-test assuming equal variance.
had the best fit. This procedure continued until no more variables could be added or removed. At each step, predictors were added if the partial correlation exceeded an F of 4.26, or removed if the partial correlation fell below an F of 4.26. This value corresponds approximately to F(0.95; 1, 23). Using these eleven regressors, the following regression equation was obtained, with $R^2 = 0.962$:

$$\text{Team MAWL} = 3.389 + 0.0285 \ (\text{Leg Strength Weaker Member}) + 0.0382 \ (\text{Grip Strength Weaker Member}) - 0.020 \ (\text{Arm Strength Weaker Member})$$

An analysis of variance on this regression model resulted in a $p<0.001$. Table 4.9 shows the t-ratios and p-values for each significant predictor. From this regression model, it appears that the weaker team member may play a role in limiting the amount of the team MAWL.

Another regression model was run which added 14 more predictors: the industrial manual material handling experience of the stronger and weaker team members, as well as 6 anthropometric dimensions of the stronger and weaker team members. These dimensions were height, weight, acromial height, biceps circumference, chest circumference, and age. After running a stepwise regression analysis with these 25 predictors, the same
Table 4.9 Results of Stepwise Regression Procedure.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coefficient</th>
<th>Standard deviation</th>
<th>t-ratio</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>3.389</td>
<td>1.442</td>
<td>2.35</td>
<td>0.029</td>
</tr>
<tr>
<td>Leg strength, weaker member</td>
<td>0.028</td>
<td>0.004</td>
<td>6.84</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Grip strength, weaker member</td>
<td>0.038</td>
<td>0.008</td>
<td>5.08</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Arm strength, weaker member</td>
<td>-0.020</td>
<td>0.006</td>
<td>-3.30</td>
<td>0.004</td>
</tr>
</tbody>
</table>
equation was obtained. Note that this last regression analysis has a high risk of instability, due to the fact that there were more predictors than data points. If a different equation had been obtained, it would have been suspect, compared to the 11 predictor model. Even the 11 predictor model would be more robust if there had been more data points.

4.5 Supplemental data analysis

4.5.1 Team lifting questionnaire

After each team lifting trial, the research participants filled out a simple questionnaire (Appendix E) which asked them to complete a sentence to indicate whether the weight just lifted was a lot less, a little less, the same, a little more, or a lot more than they could lift for eight hours under these conditions. It was hoped that this questionnaire would provide validation for a weaker member effect for any conditions where a weaker member effect was obtained. Since all conditions potentially showed a weaker member effect, the data across conditions was combined for analysis. The majority of responses (70.8%) fell into the “about the same” category. In order to test for differences in central tendencies, two median tests were run (Siegel and Castellan, 1988). The first tested whether there was a difference in central tendency between male and female responses. This test showed no significance (p > 0.05). Next, the weaker and stronger team member responses
were compared. Again, there was no difference in central tendency (p > 0.05). The results of this questionnaire provided no insight into a possible weaker member effect.

4.5.2 Final questionnaire

At the end of the four hour team lifting session, a final questionnaire was answered by all participants (Appendix F). The first two questions attempted to answer questions about the external validity of the lifting task. The first question asked which condition seemed most like an industrial lifting task. With male and female answers combined, 92% of responses indicated that the single box condition was most similar to an industrial task, and 83% of the responses indicated that the open curtain condition was most similar to an industrial task. The second question concerned the similarity of the team lifting task to the individual MAWL task. For this question, 83% said that the double box team condition was most similar to the individual MAWL task, and 58% said that the closed curtain condition was most similar to the individual task. In discussing external validity, it was conjectured that the single box, open curtain condition would have the most external validity for generalization to an industrial task, and that the double box, closed curtain condition would have the most external validity when compared to
individual MAWL tasks. These conjectures appear to be supported by the results of this questionnaire, which is summarized in Table 4.10.

The next two questions were meant to evaluate the degree to which participants felt that their contribution to the lift could be evaluated. The first of these questions asked under which conditions the participant felt that their contribution to the lift was able to be evaluated by the experimenter. For this question 75% responded that the double box condition allowed this evaluation, and 70% responded that the closed curtain condition allowed for experimenter evaluation of contribution to the lift. The last question concerned the extent to which the participants felt that their contribution to the lift could be evaluated by their teammate. To this question, 58% responded that the single box condition allowed this evaluation, and 58% responded that the open curtain condition allowed for teammate evaluation of contribution to the lift. For these questions, the double box conditions were the only ones which allowed for experimenter evaluation of individual contribution to the lift, and the open curtain conditions allowed for greater teammate evaluation of contribution to the lift (due to increased visual and auditory cues). The subjects appeared to be somewhat confused about their teammate’s ability to evaluate their contribution to the lift. Once the curtains were opened during the isolation condition, there were visual cues as to how
<table>
<thead>
<tr>
<th>Question:</th>
<th>Which condition(s):</th>
<th>Dominant Answer</th>
<th>Percent</th>
<th>95% UCL</th>
<th>95% LCL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1. Seemed most like an industrial task?</td>
<td>Single box</td>
<td>92%</td>
<td>98.7%</td>
<td>64.9%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Open curtain</td>
<td>83%</td>
<td>95.5%</td>
<td>54.5%</td>
</tr>
<tr>
<td></td>
<td>2. Seemed most like the individual task?</td>
<td>Double box</td>
<td>83%</td>
<td>95.5%</td>
<td>54.4%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Closed curtain</td>
<td>58%</td>
<td>80.5%</td>
<td>31.7%</td>
</tr>
<tr>
<td></td>
<td>3. Could the experimenter evaluate your contribution to the lift?</td>
<td>Double box</td>
<td>75%</td>
<td>88.3%</td>
<td>53.7%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Closed curtain</td>
<td>70%</td>
<td>85.5%</td>
<td>48.1%</td>
</tr>
<tr>
<td></td>
<td>4. Could your teammate evaluate your contribution to the lift?</td>
<td>Single box</td>
<td>58%</td>
<td>74.0%</td>
<td>39.9%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Open curtain</td>
<td>58%</td>
<td>74.0%</td>
<td>39.9%</td>
</tr>
</tbody>
</table>

1 UCL denotes upper confidence limit, 95%; LCL denotes lower confidence Limit, 95%. From Wierwille (1993).
much the teammate had added or subtracted, so this confusion is understandable. See Table 4.10 for further information on the responses to these questions.

4.5.3 Comments

There was a place at the bottom of the final questionnaire for additional comments on the experiment. There were only ten comments received, so they will be included here (paraphrased):

**Negative comments:**
- The foot placement was awkward
- The tables should be narrower
- The earmuffs did not muffle the sound very well
- My hands got sore
- Wrist strength seemed to be a limiting factor

**Positive comments:**
- The conditions were optimal
- The equipment was okay
- The task was easy
- Not much strain was associated with the task
- You did a good job

Other comments were received verbally during the experiment. Several of these had to do with discomfort associated with the handle design.
Several people felt that the upper table was too high to lift to and from comfortably. Several people expressed the idea that there should be cutouts at the bottom of the benches for foot placement, but it was feared that this design would make the benches unstable.
5. DISCUSSION

5.1 Social loafing and social facilitation

The hypothesized social loafing and social facilitation effects were not produced by manipulating box type and curtain condition. It was hoped that these manipulations would reproduce the effects found by both Karwowski (1988) and Johnson and Lewis (1989), and explain the conflicting results found in these experiments. Instead, all four conditions resulted in social loafing effects similar to those reported by the team lifting literature excluding Johnson and Lewis. There are three explanations for why the double box, open curtain condition could have failed to reproduce the results found by Johnson and Lewis. The first reason would be that evaluation potential has no effect in team lifting results, and that social facilitation does not occur in team lifts. This cannot be ruled out, but there are two other explanations which should be investigated before this conclusion is reached.

The first explanation has to do with differences between the Johnson and Lewis study and this experiment. In the Johnson and Lewis study the participants (all male) had to ask the experimenter to add or subtract weight. This was not the case in this experiment, and it could be that this type of experimenter evaluation potential has a large effect in producing social facilitation, possibly a greater effect than that of having a split box. In
addition, the participants could presumably hear and see their teammates asking for more weight, and these verbal and visual cues may be important. Also, Johnson and Lewis did not report whether discussion of the task was allowed between teammates. Such discussion might have encouraged competition. Another difference was that in this experiment and in the Karwowski (1988) experiment, the box lifted by the team was twice the size of the box lifted by the individual. In the Johnson and Lewis study, two boxes of the size used by individuals were attached, but they were connected by a frame that left some empty space between the boxes. This resulted in a load that was heavy on each end, instead of being evenly distributed. This could have resulted in a biomechanical advantage for the lifters in the Johnson and Lewis study that was not present in this study or in Karwowski’s. Finally, the Johnson and Lewis task was a lift and lower (no placement) in the medial plane, which is not a realistic task for team lifting. A placement to the side might have produced different results.

The other explanation is that perhaps by having all conditions run during the same session in this experiment, the participants did an outstanding job of following instructions for determining the MAWL, and so were consistent across all conditions. Participants may have been able to remember the physical sensation of the final team MAWL from one condition to the next, since conditions were not separated much in time. The
desire to perform consistently, coupled with a recent memory of the final
team MAWL under other conditions, may have counteracted the
psychosocial influence of box type and curtain condition. Perhaps if each
condition had been run on a separate day, separated by at least a week, the
memory aspect would be minimized, and a social facilitation effect similar to
that found by Johnson and Lewis would have occurred under the double box,
open curtain condition.

5.2 Weakest member effect

The t-tests that were performed comparing the team MAWL to the
doubled individual MAWL of the weaker team member indicated that there
were no significant differences between these values. Similar t-tests showed
that there were no significant differences between the team MAWL and the
sum of the individual MAWLs. The regression model can help determine
which of these may be having a larger effect on the team MAWL. The
regression model showed that there were only three significant predictors of
team MAWL, whether 11 or 25 predictors were used in the model. These
three predictors were all measures of weaker team member strength: leg
strength, grip strength, and arm strength. The fairly high $R^2$ (0.962) associated
with this model, as well as the fact that the same three predictors were
significant when the model was run two different ways, seems to indicate that
there is a limiting factor on the team MAWL. This limiting factor seems to be associated with the strength of the weaker member, although not directly related to the doubled individual MAWL of the weaker member. Since the team lifting task in this experiment was not truly a maximal task, and the task in the Sharp et al. (1993b) experiment was maximal, it could be argued that weaker member strength does play a limiting role in the team lift, but that this role is more closely related to maximal muscle strength than to the individual MAWL, which is submaximal.

5.3 External Validity

There are two areas of concern when designing psychophysical experiments for team lifting. The first is whether the techniques usually used for individual maximum acceptable weight of lift experiments can be generalized to team lifting. In a typical individual MAWL experiment, the experimenter is able to determine the exact weight lifted by the participant. Also, there is no teammate present to socialize with or compete with. In reproducing as closely as possible the individual conditions, the result was the double box, closed curtain condition. Indeed, most of the participants in this experiment felt that this condition most closely replicated the individual MAWL task. Yet neither of the earlier team lifting experiments using psychophysical methodology used this condition.
The next area of concern is whether the team lifting task can be
generalized to industrial lifting tasks. The single box, open curtain condition
was designed to be most similar to an industrial lifting task, and most of the
participants felt that this task did most closely resemble an industrial task. In
most industrial team lifting tasks the teammates also know one another
before performing the task, and this was not the case in this experiment.
Conditions were produced that were very similar to both industrial team
lifting tasks and to individual maximum acceptable weight of lift tasks.
Which condition to use in future experiments depends on the goal of the
researcher.

5.4 Posture and velocity differences

In the individual task and in the team task, participants were required
to lift the box from one bench and place it on top of another bench. However,
the posture for these tasks was not specified or constrained. In the individual
task, there was some leeway for individual posture differences. Also,
individuals could lift the box at any velocity. When the task was performed
by teams, there was less postural leeway. If one team member twisted the
load, the other team member would be forced to twist. In order to keep the
box level, the velocity of box movement had to be even between team
members. Neither posture nor velocity were studied in this experiment, and both of these may play some role in the amount of load that a team will lift.
6. CONCLUSIONS

6.1 Conclusions regarding the hypotheses

Hypothesis 1: When a psychophysical team lifting task is manipulated by changing box type and isolation condition, to enhance the effects of social loafing and social facilitation, there will be significant differences in the maximum acceptable weight of lift produced by the same team.

Conclusion: Under the conditions of this experiment, there is no significant difference in the amount of weight a team will lift when box type and isolation condition are changed.

Hypothesis 2: One of the four experimental conditions (single or double large box with either an open or closed curtain) will produce a team MAWL which is twice the individual MAWL of the weaker team member.

Conclusion: There is no significant difference between the team MAWL produced by any of the four experimental conditions and the doubled individual MAWL of the weaker team member.

Hypothesis 3: A multiple linear regression model can be developed which will accurately predict the amount of weight lifted during team lifts. The predictors for this regression model will be the whole body and
grip strengths of team members, anthropometric measurements of team members, gender, and the individual MAWLs of team members.

**Conclusion:** The only significant predictors for accurately predicting the amount of weight a team will lift are related to the strength measurements of the weaker team member.

6.2 Social loafing and social facilitation

From a team perspective, under the conditions of this experiment, only social loafing was evident. The degree of social loafing present was in close agreement with other experiments of team lifting and team strength, yet it failed to reach significance in this experiment. Social facilitation was not produced by any of the conditions, leaving the Johnson and Lewis (1989) results still unexplained. The Johnson and Lewis study should be replicated as closely as possible to see whether, given the same conditions used in that study, findings of social facilitation can be obtained. From an individual perspective, there was no significant level of social loafing or social facilitation produced by the weaker or stronger team members for the double box conditions.
6.3 Weakest member effect

This experiment provided some evidence that the amount a team will lift is limited by the weaker team member. This is in agreement with the Sharp et al. (1993) findings. This relationship should be explored further, as it is very tenuous at present. Specifically, further studies exploring the presence of a weaker member effect for maximal lifts should be conducted. If the weaker member effect for maximal lifts is reproducible, then further studies on this effect for submaximal exertions (such as team MAWL) can be conducted.

6.4 External validity

One condition had more external validity as compared to the individual task, and another had more validity as compared to the industrial team lifting task. Which is the better method? Most researchers performing team lifting research hope eventually to see their results compiled in some useful form to help industry in designing safer lifting tasks. From this perspective, the open curtain, single box condition would seem to be the desirable method for determining team MAWLs. The problem is that researchers usually compare the results of the team MAWL to the individual MAWL, even when the conditions are such that there is not much external validity between the individual task and the team task. Given that social
loafing appears to be occurring in every condition of team lifting (discounting the results of Johnson and Lewis, 1989), maybe these comparisons are unnecessary. Just perform the team lifting experiment without determining the individual MAWL first, and run enough experiments to compile as much data on team lifting under psychophysical conditions as there now exists for individual MAWLs. Comparisons to individual MAWLs should not be performed, if one is really interested in determining how much a team will lift.

6.5 General conclusions

After having completed this experiment, it seems that the psychophysical method has a place in team lifting experiments. The task can be made to be remarkably similar to industrial team lifting tasks, yet it is easy to investigate the effect of changes to the parameters of the task. One concern about using this method with defined stronger and weaker team members is that the weaker member will make a downward adjustment, and the stronger member will make a corresponding upward adjustment, and that the team will never arrive at a MAWL within twenty minutes. Instead, the prevalent adjustment strategy in this experiment was that the stronger member added weight on the light starting weight trials, and then stopped adding weight once the weaker member started taking weight out. In the heavy trials, the
weaker member took weight out until the stronger member started adding weight. Thus, even though the team members did not know that they were assigned to teams based on a weaker/stronger criterion, they were aware of their teammate's strength limitations after a few lifts. This might also occur in industry. Lifters probably have some general idea of their teammate's strength before beginning a lift, and prepare themselves accordingly.

Because of this awareness of the other person's perception of the load, and because the team lifting task can be made to have high external validity in relation to industrial tasks, team lifting experiments using the psychophysical methodology should be continued. The large single box, no isolation condition has the most external validity for industrial tasks, so this method should be used. Very little work has been done to investigate any of the human or task parameters associated with team lifting, and this could be a very fertile field of investigation for industrial ergonomists.
7. TOPICS FOR FUTURE RESEARCH

Some suggestions for further research are summarized below:

1. Repeat this experiment, except have each condition for team lifting separated by at least a week. This would test whether a memory effect is canceling out the influences of psychosocial variables.

2. Repeat this experiment with a large number of participants, to test the regression model developed in this research. This would help clarify the weaker member influence on team lifting.

3. Repeat the earlier experiments on team lifting and team strength, but this time collect data that would allow for investigation of the weaker member effect.

4. Repeat the Johnson and Lewis study as closely as possible, to try to replicate their findings of male social facilitation. If a male social facilitation effect is found, repeat the experiment with female subjects, so a gender effect on social facilitation can be explored.
5. Repeat this experiment, except measure posture differences between the individual and team trials, and investigate the results from a biomechanical perspective.

6. Investigate the effect of fatigue on team lifting by having teams continue to lift and adjust the load for 8 and 12 hours. Compare the results with those of similar experiments involving individual lifts.
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APPENDIX A

Team Lifting Experiment General Information

You are being asked to participate in an experiment to evaluate the effects of certain variables on the amount of weight teams of people will lift. This sheet should provide enough information to enable you to decide whether you wish to participate. If you do, you will be asked to fill out an informed consent form. Because this experiment involves lifting, you will also be asked to fill out a questionnaire to determine if you are at risk for injury during this experiment. If you are screened out of the experiment based on this survey, you will be compensated for your time. Otherwise, you will be accepted as a participant for the experiment.

At this point certain body measurements and strength measurements will be taken. Based on these measurements, you may be asked to withdraw from the experiment. If so, you will be compensated for your time. If the body measurements are satisfactory and you decide to continue, you will be instructed on the lifting task. You will perform a lifting task (lifting a wooden box) which will determine your maximum acceptable weight of lift. At this point, you will be lifting alone. This part of the experiment will last from one and one-half to two hours. At the end of that time, you will be paid for your participation.

You will be asked to come back a few days later for the team lifting portion of the experiment. You will be matched with one other person of your own gender, and the two of you will perform the same lifting task you performed previously, except that both of you will be lifting a box at the same time. This time there will be four conditions for the lift, and your team will perform all four conditions. It is expected that this portion of the experiment will last from three to four hours. At the end of this portion of the experiment, you will be compensated for your time, and will receive a $5.00 bonus for showing up for and completing the second session.

There are some risks associated with this experiment. Because the task involves lifting, there is always some possibility of injury. The screening questionnaire has been designed to screen out those people most at risk. The task has been designed to minimize risk. The lifting will be between wrist height and shoulder height, so there will be minimal bending of the back. Also, you will be in charge of adjusting the weight in the box, so you may lower the weight at any point in the experiment if you feel it is getting too heavy. This provides an additional safeguard against injury.

If you have any questions based on this general description, please ask the experimenter now. If not, tell the experimenter that you are ready to read and sign the informed consent form, after which you will be given the screening questionnaire.
APPENDIX B

Informed Consent Form: Team lifting experiment
Principal Investigator: Dr. Jeffrey C. Woldstad
Investigator: Suzanne E. Lee

I. The purpose of this research

You are invited to participate in a study about team lifting. The purpose of this study is to determine the effect of certain social variables on the amount of weight that a team of two people can comfortably lift for a certain amount of time under given conditions.

II. Procedures

You will participate in two sessions of research. In the first session, measurements will be taken of certain body dimensions, and whole body and grip strength will be determined. After this, you will lift and lower a box once a minute for twenty minutes, by yourself, and adjust the weight of the box according to instructions given. After a ten minute rest, you will repeat this task. Usually, two replications of this task are enough, but more repetitions may be necessary. After the first session, you will be matched with another person and will come back in for the team lifting portion of the experiment. Your will perform a team lifting task very similar to the task you performed alone in the first session. Your team will be exposed to four experimental conditions. Each condition will take about the same amount of time as the task you performed alone in the first session.

It is expected that your participation will take approximately 1 1/2 to 2 hours in the first session, and 3 to 4 hours in the second session.

The possible risk or discomfort to you as a participant may be some fatigue and low back pain. Ten minute rests will be provided to minimize fatigue. A screening questionnaire will be used to eliminate participants at risk for back injury or pain. The task will be performed between wrist height and shoulder height, to minimize bending of the back during the lifting task. Also, you may lower the weight of the box at any time, if you feel it is too heavy to lift safely.

III. Benefits of this project

Your participation in the project will provide information on the effects of social variables on the performance of team tasks. In addition, this research may lead to guidelines for safe team lifting in industry.

No guarantee of benefits has been made to encourage you to participate.

You may receive a synopsis or summary of the research results when completed. Please bring a self-addressed envelope when you return for the second session if you would like to receive this summary.

IV. Extent of anonymity and confidentiality

The results of this study will be kept strictly confidential. At no time will the researchers release the results of the study to anyone other than individuals working on the project without your written consent. The information you provide will have your
name removed and only a subject number will identify you during analysis and any
written reports of the research.

V. Compensation
If you decide to participate in this experiment, you will be paid $5.00 per hour,
for an estimated total of $25 to $30, plus a $5.00 bonus for completing the second
session.

VI. Freedom to withdraw
You are free to withdraw from this study at any time without penalty. If you
choose to withdraw, you will be compensated for the portion of time that you
completed. If you are found to be at risk for back injuries based on a screening
questionnaire, or if you are found to be outside the 25th to 75th percentile in standing
wrist height, you will be asked to withdraw from the experiment, and will be
compensated for the time you have participated.

VII. Approval of research
This project has been approved, as required, by the Institutional Review Board
for projects involving human subjects at Virginia Polytechnic Institute and State
University and by the Department of Industrial and Systems Engineering.

VIII. Participant’s responsibilities
I know of no reason I cannot participate in this study. I have the responsibility
to report honestly on the participant screening questionnaire any conditions that may
put me at risk for a back injury, or any other conditions that I feel may put me at risk for
participating in this study.

________________________________________________________________________
__________________________
Signature of participant

IX. Participant’s permission (tear off and keep this section)
I have read and understood the informed consent and conditions of this project.
I have had all of my questions answered. I hereby acknowledge the above and give my
voluntary consent for participation in this project.
If I participate, I may withdraw at any time without penalty. I agree to abide by
the rules of this project.
Should I have any questions about this research or its conduct, I will contact:

Suzanne Lee, Investigator 231-5359
Dr. Jeffrey C. Woldstad, Faculty Advisor 231-4927
Dr. Ernest R. Stout, Chair, IRB, Research Division 231-9359.
APPENDIX C

Participant screening questionnaire
Please answer each question truthfully by circling the appropriate answer. Feel free to ask the researcher if you have questions about any of the items.

Have you ever experienced back pain? Yes No
If so, were you treated by a physician for the pain? Yes No
Have you ever had a back or spine operation? Yes No
Have you experienced back pain during the last year? Yes No
If so, have you experienced pain within the last three months? Yes No
Do you have any known spinal disorders, even if they have never caused pain? Yes No
Do you have any other physical impairment, especially of the arms or upper body? Yes No
Are you currently taking any medication or drugs? Yes No

How would you rate your current physical condition? Circle one.
Excellent Good Fair Poor

How much experience do you have in manual material handling or lifting in an industrial environment? _________ months/years

Name: ___________________________ SSN: __________
Address: ___________________________

Telephone number: __________
Date of birth (month/day/year): __________
APPENDIX D

Team lifting experiment instructions

For the first part of this experiment, there will be a wooden box containing a certain amount of weight, some of which will be concealed by a false bottom. You are to imagine that you are working in an industrial environment. Your job is to lift the box from a bench at wrist height to a bench at shoulder height, and then to lower the box after three seconds. You will repeat this once every minute for 20 minutes. After every lift and lower you should ask yourself if the weight is too heavy to lift comfortably for 8 hours. Specifically:

"You are to imagine that you are being paid for the amount that you are able to lift in 8 hours, at a frequency of once per minute, without becoming fatigued or out of breath. After each lift and lower, you may adjust the weight in the box upward or downward in order to meet this criterion, using the lead shot and scoop provided. At these levels of weight, you must make a fairly significant adjustment in order to be able to detect a difference in the adjusted weight. At the end of 20 minutes, the trial will end and the final weight will be recorded. You will then perform another trial, and the average of the two trials will determine your maximum acceptable weight of lift."

These instructions will be available on a poster during the experiment to help you remember exactly what your task is. Twenty minutes is usually adequate for determining the maximum acceptable weight of lift. After the twenty minutes are up, you will be given ten minutes rest, and the experiment will be repeated. After the second trial, the experimenter may need to conduct a third trial. If this is the case, you will be given ten minutes rest and will be compensated for the additional time.

When you come back for the second part of the experiment, you will be assigned to a team. For the team lifting portion of the experiment, the instructions are exactly the same, except that the box will be larger. Each person is to adjust the weight on their side of the box whenever they feel the need to do so. Please refrain from talking to your partner during this portion of the experiment.

There will be four conditions during the team portion of the experiment. There will be two box types and two conditions of open and closed curtains. The curtains will only be closed while adjustments are being made, and will be opened during the lifting phase. In order to coordinate the team lift, a recorded cadence will be provided, "Ready, Set, Lift." Please try to follow this cadence in order to avoid the possibility of injury if one team member is unprepared when the lift begins.

After each twenty minute session of team lifting, you will be asked to fill out a short questionnaire. There will be at least 8 twenty minute sessions of team lifting, separated by ten minute breaks.
APPENDIX E

Team lifting questionnaire

You have just completed twenty minutes of lifting with a teammate. Please evaluate the final load lifted using the following questionnaire.

Place a check mark next to the answer that best completes the following sentence:

The final load my team just completed lifting represents a weight that:

_____ is a lot less than I could lift for eight hours at a pace of one lift per minute.

_____ is a little less than I could lift for eight hours at a pace of one lift per minute.

_____ is about the same load that I could lift for eight hours at a pace of one lift per minute.

_____ is a little more than I could lift for eight hours at a pace of one lift per minute.

_____ is a lot more than I could lift for eight hours at a pace of one lift per minute.

Team number:  _____

Participant number:  _____
APPENDIX F

Team Lifting Questionnaire

Final Evaluation

You have just completed eight trials of lifting with a teammate. Please evaluate the different load conditions using the following questionnaire.

Place a check mark next to the condition or conditions that best answer the following questions:

1. Of the four conditions, which condition seemed most like an industrial task? (Check only one)
   - Open curtain, single box
   - Open curtain, double box
   - Closed curtain, double box
   - Closed curtain, single box

2. Of the four conditions, which seemed most like the individual task performed in the first session? (Check only one)
   - Open curtain, single box
   - Open curtain, double box
   - Closed curtain, double box
   - Closed curtain, single box

3. During which of the four conditions did you feel that your contribution to the lift was able to be evaluated by the experimenter? (Check as many as apply)
   - Open curtain, single box
   - Open curtain, double box
   - Closed curtain, double box
   - Closed curtain, single box

4. During which of the four conditions did you feel that your contribution to the lift was able to be evaluated by your teammate? (Check as many as apply)
   - Open curtain, single box
   - Open curtain, double box
   - Closed curtain, double box
   - Closed curtain, single box

5. Comments on any of the tasks, the equipment, or the experiment in general:

   Team number: 
   Participant number: 

   109
VITA

Suzanne Elin Lee was born on May 22, 1958, in Chalmette, Louisiana. She received a B.A. in English Literature from Louisiana State University in Baton Rouge, Louisiana in December of 1980. After a short stint in Law School (also at Louisiana State University), she worked in industry for several years, including several years in the Industrial Engineering department of a large Hercules, Inc. manufacturing facility. She entered the graduate program in Human Factors Engineering (safety engineering option) at Virginia Tech in the fall of 1993. Suzanne served as a graduate teaching assistant in the spring of 1995 for the course “Introduction to Human Factors.” Her research interests include industrial ergonomics, safety, and handedness. She is an active member of the Human Factors and Ergonomics Society and of the American Society of Safety Engineers.

Suzanne Lee