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The Ringelmann Effect: Studies of Group Size and Group Performance[1]

ALAN G. INGHAM
University of Washington

AND

GEORGE LEVINGER,[2] JAMES GRAVES, AND VAUGHN PECKHAM
University of Massachusetts, Amherst

Ringelmann's classic finding—that the addition of co-workers in a rope-pulling task leads to a linear decrement in the individual group member's average performance—was reexamined experimentally. Study I attempted to replicate the effect, using groups of subjects ranging in size from 1 to 6. Performance dropped significantly as group size was increased from one individual to two or to three, but the addition of a fourth, fifth, or sixth member produced insignificant additional decrements; thus, the effect was not linear but curvilinear. Study II was designed to examine possible sources of performance loss, separating the factors of "coordination" and "motivation" loss (Steiner, 1972). The possibility of intermember incoordination was eliminated, while motivation loss remained free to vary: Each experimental subject pulled alone, and in "groups" where he believed there were from one to five other members. Once again, individual performance declined significantly with the addition of the first and second perceived co-worker, but then leveled off for perceived group sizes three to six. Some implications are discussed.

In 1927, the German industrial psychologist, Walther Moede, reported an interesting finding obtained by his student Ringelmann. According to Moede, Ringelmann had observed that when groups of co-workers pulled on a rope, their collective group performance was inferior to

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[2] Requests for reprints should be addressed to George Levinger, Department of Psychology, University of Massachusetts, Amherst, MA 01002.

the sum of their individual performances. As groups increased in size in the tug-of-war (rope pulling) task, the discrepancy between a group's actual performance and its potential performance increased progressively. If we assume that one person individually performed at 100% of his ability, members of Ringelmann's dyads performed at 93% of their potential average ability, members of his triads at 85% of their potential average ability, and members of his groups of eight at a mere 49% of their average ability (Moede, 1927, p. 200). Apart from Moede's summary description, we have been unable to find any additional information about the Ringelmann study despite its widespread citation in American literature on group performance (Dashiell, 1935; Davis, 1969; Steiner, 1966, 1972; Zajonc, 1966).

In the context of recent theoretical developments (Steiner, 1972), Ringelmann's study has assumed renewed significance. Steiner suggested that productivity is dependent upon three factors: task demands, individual and group resources, and the process by which resources are mobilized. Thus, a knowledge of task demands and of group members' resources indicates a group's potential productivity. The discrepancy between a group's actual productivity and its potential productivity, therefore, may be attributed to faulty social process. Since Ringelmann's task is unitary, additive, and maximizing (Steiner, 1972), it permits a linear projection of a group's potential productivity. And, since task performance relies solely upon the individual members' resources, rope-pull data are not complicated by extraneous factors as are data from other unitary additive tasks such as rowing (in which performance is affected by shell size, crew weight, and water displacement). In additive tasks like Ringelmann's, the separate members' efforts are combined through social coordination. As group size increases, the number of "coordination links" and thus the opportunity for faulty social process increases; hence, the greater becomes the discrepancy between actual and potential group performance. The Ringelmann study, then, demonstrated dramatically how the efficiency of the member may decrease purely with the enlargement of group size—even though the total group output increases. Finally, Ringelmann's task has significance for methodological reasons: it is a situation that strongly involves subjects without recourse to deception and it yields ratio measures of individual and group output.

Despite those interesting features, the Ringelmann rope-pull paradigm has not been used in later research on group performance. Faulty social process, due to losses in either coordination or motivation, has been investigated primarily in the context of intellective problem solving (Davis, 1969). Because of that, and also because Moede's original report of

Ringelmann's finding was scanty—giving no more information than that mentioned in our first paragraph—it remained unclear as to whether the effect was replicable, how it might be affected by differences in procedure, in subject selection, or in other sorts of group conditions. We were led, therefore, to an interest in replicating and extending the Ringelmann effect, with a view to its eventual usefulness for testing more general models of group performance.

OVERVIEW OF RESEARCH

Two pilot studies to replicate Ringelmann's work were done first, one with four six-man groups of college students and a second with seven six-member groups of young boys. These pilot studies revealed that our procedure was satisfactory and they yielded some preliminary results showing the existence of noticeable decrements after the addition of a second and of a third co-worker; further additions resulted in only minor performance decrements. Subsequently, the main replication (Study I) was undertaken with 17 six-man groups of college students. In these studies, the only experimental variation was the size of the pulling group—varying between one person pulling alone and all six group members pulling together. The questions to which we sought answers were: (1) Would there be a linear decrease in the amount pulled per person as group size increases? (2) If the results should not parallel those of Ringelmann, what would be the best description of the functional relationship between member output and group size?

The output losses found in the replication research left us interested in the reasons for the decrement in group member performance. Therefore, Study II was designed to examine two alternative explanations of the source of process loss: coordination versus motivation loss. Details are reported below.

STUDY I: AN ATTEMPT TO REPLICATE THE RINGELMANN EFFECT

Moede's (1927) report gave no information about Ringelmann's procedure for determining pulling performance. A number of factors may not have been controlled at that time, including subjects' slippage while pulling, their angle of pull and their effort of holding up the rope. Nor do we know about the reliability of measurement of pulling performance. Our apparatus was designed, therefore, to minimize slippage and angular variation, and to maximize reliability of measurement.

Apparatus

A wooden framework was built with six pulling stations at 3-ft intervals (Fig. 1). The total length was 27 ft (8.24 m). It would have been preferable to have eight

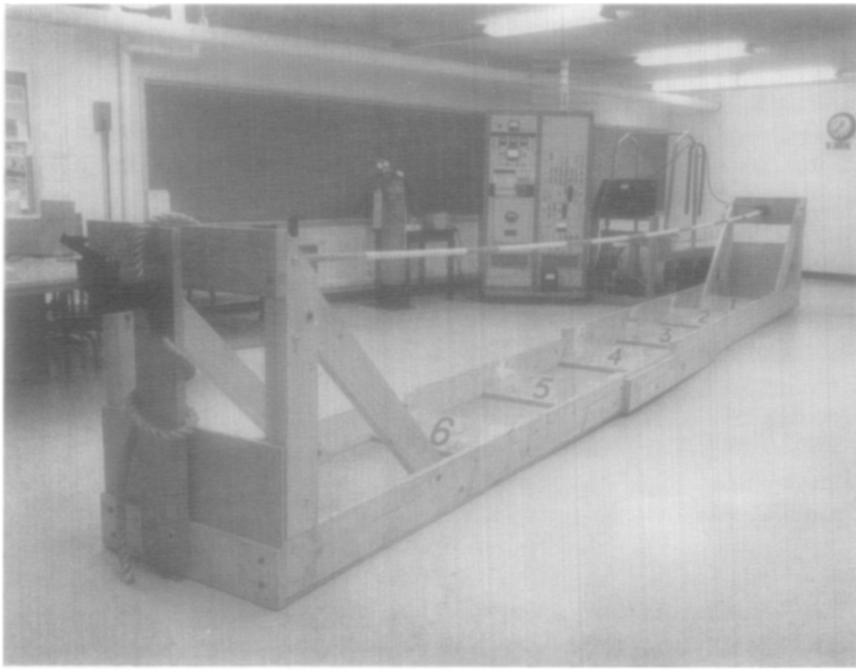

FIG. 1. Rope-pull apparatus.

pulling stations, as in the Ringelmann study, but it was not feasible to house an apparatus longer than the present one. The rope was placed at a height of 3 ft 3 in. (1 m), the standard height of a doorknob: it was attached by an eye-bolt to a Baldwin-Lima-Hamilton strain gauge (BLH Load Cell U 361) at the front of the framework.

1. *Reduction of slippage.* To ensure that the subjects' feet would not slip, footrests were placed across the floor of the framework. Each puller's front foot could, therefore, be planted securely on a footrest angled at 45°. To permit a firm grip on the rope and to control where different subjects pulled, the rope was covered with athletic tape at regular intervals.

2. *Support of rope.* The framework contained a manila rope, 1⅛ in. (2.86 cm) thick. To control the pulling angle, as well as the weight that different-sized groups had to support, a gear-toothed crank at the rear of the framework held the rope rather taut (Fig. 1). With the rope maintained at a constant tension, subjects did not have to divert effort into lifting its weight, but could concentrate entirely on their pull.

3. *Reduction of measurement error.* Pulling scores were recorded electronically. Strain transmitted along the rope caused an electrical signal to be emitted by the BLH strain gauge. This signal was transmitted via an Accudata-195 Gauge Control Unit to the Honeywell Visicorder (Model 1508) recording oscillograph. Contained within the recording apparatus was a Honeywell galvanometer (Model M 40 350 A was used in Study I; a more sensitive model, M 24 350, was used in Study II).

Variations in pull transmitted from the BLH strain gauge produced differential deflections on the mirror surface of the galvanometer, and were recorded in millimeter deviations upon an oscillograph. In order to transform these millimeter deviations into an index of "poundage pulled," the strain gauge was calibrated up to 1000 lb of pull.

Subjects

The subjects in Study I were 102 male students from the introductory psychology course at the University of Massachusetts, who received extra credit for their participation in the experiment. They were scheduled to arrive at the laboratory in groups of six. Upon his arrival each subject was given an identification tag containing a letter from A to F.

Design

A treatment-by-subjects or repeated measures design (Winer, 1962, pp. 105–124) was used in this study. To negate any residual effects, due to either fatigue or practice, the pulling order was randomized prior to the testing of each group. Since the task induced fatigue, the design tried to ensure: (1) that all subjects pulled an equal number of times; (2) that each subject had approximately the same rest interval between pulls; and (3) that the number of pulls per subject was at a minimum. Subjects were assigned to the various group sizes on the basis of a partial permutation (see Table 1). Thus, in group size 6, all subjects were involved in the task; in sizes 5 and 4, each subject rested once while the others pulled; in size 3, each person pulled thrice and rested thrice; in group size 2, each subject rested twice while others pulled; in the individual condition, subjects took turns at pulling while all others rested. Tracing any subject through the illustrated treatment sequence reveals that the total number of pulls per subject was 13 and the total number of rest intervals was 12.

To minimize the effects of pulling position, the subjects were randomly assigned to their tug-of-war stations in each treatment. Since each subject had a letter iden-

TABLE 1

SUBJECT COMBINATIONS USED FOR ALL GROUPS IN THESE STUDIES

Number of individuals in pulling unit					
6	5	4	3	2	1
ABCDEF	BCDEF *A*[a]	CDEF *AB*	CDF *ABE*	CD *ABEF*	C *ABDEF*
	ACDEF *B*	ABEF *CD*	CDE *ABF*	EF *ABCD*	D *ABCEF*
	ABDEF *C*	ABCD *EF*	BEF *ACD*	AB *CDEF*	E *ABCDF*
	ABCEF *D*		AEF *BCD*		F *ABCDE*
	ABCDF *E*		ABD *CEF*		A *BCDEF*
	ABCDE *F*		ABC *DEF*		B *ACDEF*

[a] Subjects with identification letters in italics are resting.

Note: Mean individual scores were obtained by dividing pull scores in each condition by the number of individuals pulling. Thus, for each group of subjects, six such scores were computed: The mean pull for sizes 1, 2, 3, 4, 5, and 6. These six scores were the data items used for the analysis of variance.

tification tag and each pulling station was numbered, the assignment of subjects to stations was accomplished by the experimenter calling out a series of letter-number combinations—for instance: "A goes to 5, B goes to 1, ..." In this example, subject A would position himself at pulling station 5, B at station 1, and so forth, until all co-workers had been assigned.

Instructions

A model first demonstrated the standard tug-of-war stance. The following instructions were then given:

> "This apparatus is designed to test your pulling power. You will be tested alone and in groups of various sizes. This is not a competition and no results will be given you until the required number of pulls are completed. You will be given three commands:
>
> (1) *'Take the Strain.'* During this phase, you will have time to secure a grip on the rope and adjust your foot position. One foot must be placed on the number in the center of the footrest and your other foot on the baseboard;
>
> (2) *'Pull!'* During this phase you are required to pull as hard as you can for a period not exceeding 6 sec. Pull along the line of the rope. Do not pull down or to the side, but attempt to remain in the required stance. (A second demonstration of the correct and incorrect methods of pulling was given by the model.)
>
> (3) *'Rest'*—You may return to the standing position and recover from your exertions."

At this point, the experimental commands were given to the model in the way they would be given during the experiment. This was the final demonstration that subjects received.

Results

Figure 2 shows the percentage of loss in mean individual pulling performance across all conditions of group size. The assumed near 100% efficiency in the alone condition was equivalent to 130 lb/(59 kg).[3] A marked drop in average member efficiency resulted from the addition of one and of two co-workers: 9 and 18%, respectively. Further additions of co-workers, however, produced only small additional decrements. While three persons' performance was reduced to 82% of their average individual efficiency, a group of six pulled at an average of 78%—hardly much less.

To examine the significance of these effects, a treatment-by-subjects analysis of variance was performed. Athough the treatment orders (size

[3] The data are reported in percentage-of-performance-lost in order to facilitate comparison between our two studies and that of Ringelmann. A second reason for reporting percentages is that we are more confident of the within-study than the between-study comparisons of actual poundage pulled. After Study I, we discovered a malfunction in the voltmeter used to standardize the signal span; it had consistently reduced the sensitivity of the gauge control unit by about 23%.

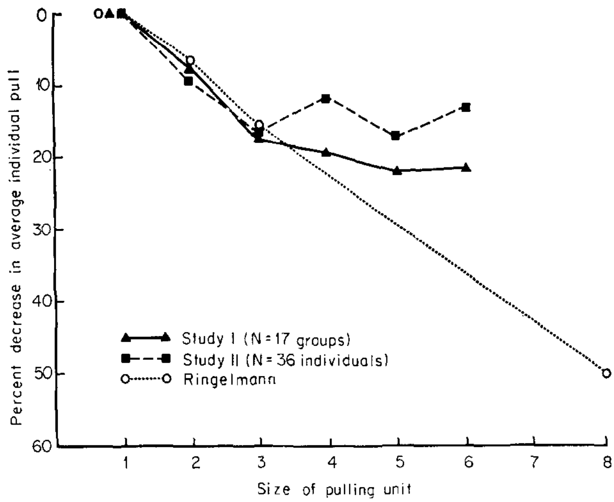

FIG. 2. Mean individual pull scores according to group size.

of pulling unit) had been randomized to negate the influence of practice and fatigue, the randomization was not systematic and, hence, the data were not amenable to a Latin square analysis which would have yielded further information. The treatment-by-subjects design, however, provides a more conservative estimate of variability due to experimental conditions than does the Latin square in that the variance due to order effects is lumped together with the variance due to error. A summary of the analysis is presented in Table 2; it indicates that at least one treatment mean differed significantly from the others ($F = 26.36$, $p < .01$). To find out which of the six means actually differed significantly, a Duncan's Multiple Range Comparison was performed. This analysis

TABLE 2
SUMMARY TABLE OF ANALYSIS OF VARIANCE AND TREND ANALYSIS: STUDY I

Source	*df*	*MS*	*F*
Subjects	16	1113.242	
Treatments	5	1389.528	26.36**
Linear	1	5800.725	110.06**
Quadratic	1	1038.149	19.70**
Cubic	1	0.174	
Remainder	2	108.591	
Error	80	52.705	

** $p < .01$.

revealed that the means for treatment sizes of 1 and 2 differed significantly from each other, and from every other treatment mean ($p < .01$):

$$T_1\ T_2\ \underline{T_3\ T_4\ T_6\ T_5}$$

The mean scores of pulling unit sizes 3 through 6, however, did not significantly differ from each other.

The results of the multiple-range test were confirmed by a trend analysis in that both significant linear ($F_{lin} = 110.66$; $p < .01$) and quadratic ($F_{quad} = 19.70$; $p < .01$) trends were obtained. Thus, the Ringelmann effect was only partially replicated. The present findings confirmed the results of our two pilot studies.

STUDY II: MOTIVATION AS A SOURCE OF PROCESS LOSS

Neither the pilot nor main replication research could reveal the source of decrement in group members' performance. On an additive task, the addition of new members to a group increases its resources and, therefore, its potential performance. But such additions also increase the possibility of process loss due to either lack of coordination and/or declining motivation (Steiner, 1972). Thus, we asked whether, as group size increased, the output loss was mainly due to increasing problems of synchronizing the members' efforts or whether such losses resulted from reductions in personal exertion.

To separate these two distinct sources of process loss, the following study was designed: Only the individual's perception of group size was varied, while keeping constant the fact that he was really pulling alone. Thus, motivation losses due to perceived size remained free to vary, while coordination losses due to actual group size were eliminated. Individual subjects were to be recruited for the rope-pulling experiment as before, but the remaining "subjects" were to be experimenter confederates.

Subjects

Forty-one male students were recruited from the introductory psychology course at the University of Massachusetts. Five subjects did not adequately follow the instruction, "pull without jerking the rope"; data from only 36 subjects, therefore, were retained for analysis.

The five confederates who served as pseudosubjects were trained merely to give the impression of pulling so that the naive subject would be measured while he perceived himself to be functioning in groups of various sizes. To create the image that they were also "pulling," the pseudosubjects were trained to produce the appropriate kinesthetic feedback necessary to convince the naive subject. The naive subject was always assigned to pulling station 1, and the pseudosubject who stood immediately behind him created a sway in the rope. Pretests had shown that a sway of only 1 or 2 in. was enough to create the impression that others were also pulling, without affecting the strain on the rope measured by the load cell. Coupled with occasional sounds of physical exertion, this sway convinced all naive subjects of the reality of their co-workers' "efforts."

Design

A treatment-by-subjects design was again used. As in Study I, the treatment orders were randomized prior to each experimental session to negate any systematic residual effects of one treatment upon another.

To maintain the credibility of the pseudosubjects and also of the instructions, the subjects (naive and pseudo) were assigned to groups according to the partial permutation used in Study I (Table 1). To further disguise the facade, all subjects (naive and pseudo) were asked to put on blindfolds when they were assigned to a pulling station; the pretext was that we were testing effects of "visual feedback" on group performance. Whenever the naive subject was assigned to pull, the pseudosubjects refrained from pulling as previously discussed. However, when the naive subject had a rest period and was allowed to remove his blindfold, the pseudosubjects taking their turn on the rope exhibited maximal exertions.

Procedure

The apparatus and procedure were similar to that of the earlier work. Since more sensitivity was needed to measure the smaller, purely individual, performance, a more sensitive galvanometer (Honeywell Model M 24 350) was substituted for the one used previously.

The use of the blindfolds required explanation. Thus, the following orientation statement was included in the subject's initial instructions:

"In this experiment, you will be asked to pull on a rope as individuals and as members of groups varying in size. You are instructed to pull as hard as you possibly can without jerking on the rope. Your eyes will be covered by a blindfold before you are given the command to 'take the strain,' and they must remain covered until the end of each pull. The reason we are using blindfolds is to compare the effect of 'no visual feedback' upon the pulling strength of individuals with data compiled earlier when 'visual feedback' was allowed. You will be given three commands . . ."

After the completion of the experiment, subjects were debriefed as they had been in the earlier studies. It is notable that in no single instance had any naive subject become suspicious of the proceedings. During the postexperimental explanation session, subjects often laughed with great surprise upon hearing how they were led to believe that other group members were pulling behind them.

After each subject's participation, both he and the pseudosubjects left the laboratory through an exit door. The pseudosubjects filtered back individually to take part in the next subject's pulls. If the next naive subject had already arrived, pseudopartners would come in with naive questions such as "Is this the room for the psychology experiment?" Occasionally, a confederate would arrive late and apologize for delaying the experiment.

Results

Figure 2 shows the mean pull scores for individuals who pulled in what they believed were groups of varying size. The assumed 100% efficient performance in the alone condition was equivalent to a mean

TABLE 3
Summary Table of Analysis of Variance and Trend Analysis: Study II

Source	*df*	*MS*	*F*
Subjects	35	5140.364	
Treatments	5	2574.390	11.51**
Linear	1	6848.826	30.61**
Quadratic	1	4096.889	18.31**
Cubic	1	282.668	1.26
Remainder	2	821.784	
Error	175	223.742	

** $p < .01$.

pull of 131 pounds (59.47 kg). Once again, these data indicate a clear drop in performance, corresponding to the addition of one or two perceived co-workers. However, after the addition of the second co-worker, there was no further decrease in the group's pulling scores. While three persons pulled at 85% of their average individual efficiency, a group of six still pulled at an average of 86% (Fig. 2).

A Treatment × Subjects design was again employed in the analysis of the data. The data points for this analysis were the mean individual performance scores for each "group" size. A summary of the analysis of variance is presented in Table 3; it shows that at least one cell treatment mean differed significantly from the others ($F = 11.51$; $p < .01$).

To find out which of the six treatment means actually differed significantly, Duncan's Multiple Range Comparison was performed; it revealed that the mean for the "size 1" treatment differed significantly from all other means. Furthermore, the "size 2" mean differed significantly from those for

$$T_1\ \underline{T_2\ T_4\ T_6}\ T_3\ T_5$$

group sizes 1, 3, and 5 (but not from those of sizes 4 and 6). The results of the multiple range test were confirmed by a trend analysis in that both significant linear ($F_{\text{lin}} = 30.61$; $p < .01$) and quadratic trends ($F_{\text{quad}} = 18.31$; $p < .01$) were again found. Both the multiple range and trend analyses support the interpretation that subjects lost some motivation as soon as they perceived that even one "co-worker" was added.

DISCUSSION

The findings of both studies indicate that individual performance on the rope-pull task declined substantially when subjects either were or believed that they were members of a group of co-workers. To that extent, these results offer a partial confirmation of the Ringelmann effect.[4] In these studies (and also in our two pilot studies) the average individual's output declined 15–18% from his performance in the alone condition to his performance in the three-man group. Beyond group size 3, however, the addition of further co-workers failed to produce continued performance decrements as appeared to occur in Ringelmann's initial research. (Only in the second pilot study, where our subjects were young boys, was there an almost linear decrement with the addition of co-workers beyond group size 3.)

The present departure from the continued linear decrement observed by Ringelmann may simply be due to the tighter controls and improved apparatus design of the present studies. For one thing, the experimental controls placed on the subjects—such as when to pull, and how long to spend pulling—may have reduced incoordination from lack of leadership. Furthermore, incoordination problems due to differing angles of pull, differential weight of rope per puller, and slippage of feet or hands were minimized in our apparatus. As a result, purely mechanical sources of process loss were probably less than those of Ringelmann. Our conjectures about differences are tentative, however, because of the inadequate report of Ringelmann's experimental design in Moede's (1927) article. Certainly, the results of Study I (Ringelmann Replication) do not allow us to specify any group size where the further addition of co-workers will fail to increase total output. Such a point of diminishing returns was suggested by Rühlmann (1900) who, in observations of the additive task of rowing, noted that the eight is the largest boat in rowing since larger boats are inefficient. Rühlmann cited the example of a canoe with 24 paddlers which travelled around Lake Wannsee in Berlin no faster than another with a crew of eight. A point of diminishing returns is also suggested by an imaginary extension of Ringelmann's 7% decrement to a hypothetical group size 15, where the addition of a sixteenth member would presumably add nothing more to the group's output (Zajonc, 1966, p. 102–103), or where 50 co-workers would supposedly reach zero effectiveness (Dashiell, 1935, p. 1113).

[4] It is worth noting that the effect is not necessarily confined to the performance of humans. Thus, Koehler (1927) reviews data from two different studies where performance decrements were found among horses, when pulling teams were increased in size. And J. H. Sudd found that groups of ants pulled their prey with measurably less average force than did individual ants: "For individual ants the weight of prey was about 85 milligrams . . . two ants operated at about 94 per cent efficiency, and three and four at 77 per cent efficiency" (cited in Zajonc, 1972, p. 16).

Although the results of Study I established an inverse relationship between group size and individual performance, they gave no clue about the possible sources of performance loss. It remained unclear whether group members pulled less hard because of incoordination or because of losses in motivation. Study II, then, aimed to separate these determinants of process loss; the possibility of coordination loss was eliminated so that motivation effects could be isolated. Although minor procedural differences negate a strict comparison of the two studies, Study II again demonstrated a curvilinear relationship between group size and individual performance. So that while Steiner (1972) attributed Ringelmann's results mainly to increasing difficulty in intermember coordination, Study II shows that declining motivation itself has a deleterious effect on productivity.

What influences would account for the motivation loss apparent in Study II? One possible explanation can be derived from the absence of feedback. There was neither kinesthetic feedback associated with overcoming an object's inertia—since the rope was stationary on an immobile framework—nor comparative feedback—since the experimenters did not inform subjects of the pull recorded by the load cell on successive trials. It is possible, then, that the absence of cognitive feedback reduced performance levels from that which could have been achieved under feedback conditions (see Zajonc & Brickman, 1969).

A second explanation for motivation decrements would be that subjects felt less responsibility when pulling with others than when pulling alone. The task permitted the individual to "hide in the crowd" as the group size increased (Davis, 1969, p. 72). Either unintentionally or intentionally, subjects may have reduced their effort when they felt less personally responsible for the performance (see also Latané & Darley, 1970). Should the subjects have been cognizant of the anonymity provided by the addition of co-workers, they might have engaged in "impression management" (Goffman, 1959). That is, when it was possible for the experimenter to estimate individual scores, a maximal effort appeared necessary. Under group conditions, however, an individual's separate pull was unascertainable, and subjects may have given convincing impressions of straining hard while actually pulling with less than their maximum strength.

The present results, then, tend to confirm the generality of the Ringelmann phenomenon—increases in group size are inversely related to individual performance. Our results also illustrate Steiner's (1966, 1972) assertion that both coordination and motivation are determinants of process loss in group performance. And, they have interesting implications for other research on group performance. For example, Zajonc and

Brickman (1969) in their analysis of expectancy (an emphasis on cognitive process) and aspiration (implied motivational forces), note that "it has not been illustrated that setting a goal has in and of itself motivational consequences." In our initial study, subjects had no knowledge of results and were thus denied the possibility of goal setting behavior. Thus, the discrepancy between potential and actual group performance may have been due purely to incoordination. However, if Ringelmann's subjects knew the results of their efforts, then such knowledge of results may have contributed to decreased motivation. That is, since increases in group size reduced actual performance from what was potentially expected, Ringelmann's subjects may have shifted their expectations to bring them closer to their feedback—namely, downward. Such reasoning might account for the difference between the results of our study and those obtained by Ringelmann. Thus, the question remains begging: If the knowledge of results were manipulated to induce subjects to set higher goals, would the discrepancy between actual and potential performance be reduced? That is, if the experimenter gave feedback of favorable pull scores, would subjects exert themselves to greater performance levels? The implication for future research is to ask "what kinds of expectancies are optimal for performance in the long run as well as the short run, with differing degrees of risk and failure. . . ." (Zajonc & Brickman, 1969, p. 155).

Our research suggests a second avenue for inquiry. Since the groups used in our experiments were quasi-groups, incoordination problems would probably be greater than in established groups who are used to working together. One might ask whether the discrepancy between actual and potential productivity would be reduced if our subjects had been team members on the same rowing crews. Inspection of the times of recent Olympiads (1952–1964) reveals that coxed fours were, on the average, only 13% faster than coxed pairs, and eights were only 23% faster than pairs. In the 1972 Olympiad, the winning time for double sculls was only 4% faster than for single-man boats, while the fastest coxed eight rowed only 6% faster than the fastest coxed four. However, as previously noted, such times are not directly comparable because of variations in shell size, crew weight and water displacement. What would occur, though, if such crews after having had many practice sessions for coordinating their efforts, were placed on the rope-pulling apparatus where extraneous factors such as those identified above were negated? What are the effects of practice, learning, and incentive on the discrepancy between actual and potential performance? Furthermore, regarding the results of our second study, it may be asked whether members of established teams—compared to members of quasi-groups—

would be significantly less likely to reduce their personal efforts under conditions of responsibility diffusion. These and other questions await future research.

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