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Investigation of the Effects of Extravehicular Activity (EVA) Gloves on Performance

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Introduction

Human capabilities such as dexterity, manipulation, and tactile perception are unique and render the hand a very versatile, effective, and multipurpose tool. This is especially true for the EVA microgravity environment. Under these conditions, the hand becomes the primary means of locomotion, restraint, and material handling. Facilitation of these activities and simultaneous protection from the hazards of the EVA environment are often conflicting objectives of glove design. The conflicts associated with providing primary hand protection through use of gloves while permitting adequate hand functioning have been widely recognized.

Many articles have been published concerning the effect of gloves on task performance. Lyman and Groth (1958) reported that, when gloves were worn, subjects exerted more force than when bare-handed while inserting pins into a pegboard. Bradley (1969) studied the operation time of five types of control tasks with bare hand, wool gloves, and leather over wool gloves. The results of his research showed that the operation time depends on the type of gloves, the type of control operations, and the physical characteristics of the controls. Cochran et al (1986) studied grasp force degradation of some commercially available gloves. Five types of gloves and bare hand conditions were compared and the results showed that all the gloves tested reduced the maximum grasp force significantly when compared to bare hand condition. Wang et al (1987) also found similar results. The basic overall findings of these studies are that gloves reduce strength capabilities and that gloves reduce dexterity and manipulation.

While most of the studies have addressed performance compromises with commercial gloves, very few studies have attempted to assess the effects of EVA gloves on basic hand capabilities. Perhaps the most comprehensive study performed on the assessment of performance decrements with EVA gloves is the one done by O'Hara et al (1988). The authors studied two levels of hand conditions (gloved and bare-handed), two levels of pressure differential (0 psid, and 4.3 psid), and three levels of hand size (small, medium, and large). Eleven subjects participated in an experiment in which six categories of performance measures were recorded: 1) range of motion, 2) strength, 3) tactile perception, 4) dexterity, 5) fatigue, and 6) comfort. The salient findings were the following:

1. On the range of motion, the glove and pressure effects were diverse and motion dependent. Effects for flexion were different than that for extension.

2. Gloves reduced basic hand grip strength and the pressure differential reduced it further. However, neither the glove nor the pressure had any effect on pinch strength.

3. The degradation in tactile perception was more noticeable with glove use than with pressure change.

4. Dexterity was reduced by both glove use and pressure. Unpressurized glove use reduced dexterity by 50%, while pressurizing reduced it further by 30%.

5. The fatigue effects were most uninterpretable due to complex electromyogram (EMG) signatures at different test conditions.

6. Perceived comfort reduced by 100% with unpressurized gloved conditions. Pressurizing reduced it further by 600%.

The rationale for this investigation evolved out of the above study. The O'Hara (1988) investigation used one type of glove and one pressure level. It is recognized that, in EVA tasks, the prebreathe time before donning the suit is a function of the pressure. Prebreathing is an activity performed before donning the space suit for EVA activities to let the body achieve new physiological homeostasis for activities at new, lower pressure; the greater the pressure, the shorter the prebreathing time. However, the performance decrement is also a function of pressure, with larger decrements at greater pressure. Important information that is needed but is currently unavailable is the pressure performance profile for the various EVA gloves.

Therefore, the objective of this study was to develop functional relations between performance decrements and pressure differential for EVA gloves. A factorial experiment was performed in which three types of EVA gloves were tested at five pressure differentials to assess the effects of EVA gloves at different pressures on human hand capabilities.

Methods

Subjects

Six voluntary subjects (three males and three females) participated in this experiment in which a number of strength and dexterity measures were recorded.

Independent Variables

The independent variables tested in this experiment were gender, glove type, pressure differential, and glove configurations. The six subjects were equally split between two genders to provide the gender differences. Two types of glove assembly were used: with and without thermal micrometeorite garment (TMG). An EVA glove is an assemblage of two major units: an inner pressurizing glove and an outer TMG glove. One of the objectives was to assess the exact effect of TMG on performance. Current shuttle gloves operate at 4.3 psid. Certain developmental gloves are being designed to operate at 8.3 psid, the rationale being that operating at higher pressure differentials results in the pre-breathing time being reduced considerably. Five levels of pressure differentials were used in this experiment: 0 psid, 3.2 psid, 4.3 psid, 6.3 psid, and 8.3 psid. The intent was to develop a pressure-performance decrement profile. Three different glove configurations were tested here: current shuttle 3000 series weightless environment training facility (WETF) training gloves (referred to hereafter as glove C) and two advanced developmental gloves (referred to hereafter as gloves A and B). To summarize, the independent variables with their respective levels were

1. Gender	male and female
2. Glove type	with and without TMG
3. Pressure (psid)	0, 3.2, 4.3, 6.3, 8.3
4. Glove configuration	A, B, and C

Performance Measures

The performance measures were selected based on the O'Hara (1988) study, and comprised two strength measures (grip and pulp pinch strength), two dexterity measures (nuts-and-bolts test and knot-tying test), and a tactility measure (two-point discrimination (2PD) test). The criteria for selection of performance measures were that they be generic and hence repeatable, and that they be reasonably representative of the EVA activities. The grip strength was measured by a standard JAMAR hand dynamometer. The dynamometer was wired to a digital display, which gave the grip strength readings in pounds. The grip span of the hand dynamometer was kept constant throughout the experiment at 2 inches. The pinch strength was measured by a B&L (60 pounds) pinch gauge. Dexterity and manipulation were measured by the knot-tying test and the nuts-and-bolts test. The former consisted of pushing a rope through a hole on a wooden panel and tying a shoelace knot around the panel. In order to gauge the size effect, ropes of three sizes (small, medium, and large) were used. The time to tie the knot was recorded as a performance measure. The wooden panel had three holes through which three pairs of nuts and bolts (small, medium, and large) were assembled. The nuts-and-bolts assembly task consisted of undoing the nut from the assembly, showing the nut and bolt to the test experimenter, and reassembling the nut and bolt on the wooden panel. The mean assembly time was recorded and used as a measure of dexterity. The final measure recorded in this experiment was the performance in the modified 2PD test. O'Hara et al (1988) had used a modified version of a 2PD test for assessing the tactile sensitivity of subjects under different test conditions. A similar apparatus was fabricated here to measure the tactile sensitivity. In essence, the apparatus consisted of a "V" block through which the subjects had to slide their fingers. The "V" block was graduated, and the distance from the starting end to the point where the subjects could feel two edges was treated as the tactility score. As the force with which the subjects could press the "V" block was an uncontrollable variable which could influence the results, the "V" block design used by O'Hara et al (1988) was modified to have a balancing weight on the underside of the apparatus. The dead weight was expected to facilitate constant application of force on the "V" block during the administration of the 2PD test.

Glove Box

Testing was performed in the Advanced Suit Laboratory in Building 34. The actual tests were conducted inside a glove box (figure 1). The glove box is cylindrical in shape, approximately 2 ft in diameter and 4 ft in length with an internal volume of 13 ft^3. On each sides of the glove box are two end caps, made of Plexiglas and bolted through 8 bolts. About midway along the axis of the glove box are two 6-in. circular openings in the cylinder wall, placed shoulder-width apart, which provide access and attachment points for the EVA glove and arm assemblies. The glove box was connected to a vacuum pump and could be evacuated to the desired pressure level. There was a gauge on the outer cylinder wall calibrated to read the pressure differential.

Procedure

The levels of independent variables were factorially combined to yield 26 experimental conditions. The order of presentation of these 26 experimental conditions was randomized for each subject (see table 1).

Table I. Experimental Design

GLOVE CONDITIONS						
PRESSURE	A	A with TMG	B	B with TMG	C	C with TMG
0 psi						
3.2 psi						
4.3 psi						
6.3 psi					NA	NA
8.3 psi					NA	NA

In addition, all the subjects performed a 'bare-handed' condition test on the last day. Within a condition, the order of presentation of the five tasks (grip, pinch, nuts-and-bolts, knot-tying, and 2PD) was also randomized for each subject. As stated earlier, six subjects participated in this study. Gender was a between subject factor. Each subject performed one condition per day, resulting in 26 days of experimentation in all. A trial consisted of the following steps:

1. The glove box was pressurized to the required level.
2. The subject donned a pair of comfort gloves and the EVA gloves for that day's trial.
3. Grip strength was recorded through a JAMAR Hand Dynamometer connected to a digital display and to a Teac Recorder.
4. Pulp pinch strength was measured following a 2-minute rest period using a pinch gauge.
5. For the nuts-and-bolts test, three pairs of nuts and bolts (large, medium, and small sizes) were mounted on a wooden panel. The task involved removing the nut from its respective bolt, and mounting the nut back again. The time for this activity was recorded with a stop watch.
6. The knot-tying test consisted of tying a simple shoelace knot on the same wooden panel that had the nuts and bolts. Three sizes of ropes (small, medium, and large) were used and the time to tie was recorded with a stop watch.
7. The 2PD test consisted of the subjects sliding their right index finger along the edges of the "V" block. The distance of the point at which they felt two edges from their staring point was recorded as their

tactility score. In order to keep the force at the point of contact constant, the "V" block had a balancing weight on the other side.

Figure 1 shows the sketch of the experimental setup with nuts-and-bolts panel. Figure 2 shows the sketch of the three gloves tested. A trial lasted for about 20 minutes.

For purposes of clarity, the data was analyzed first with strength as dependent measures, and then with dexterity measures as dependent variables.

Results

This study had a number of performance measures. The results will be presented under two headings: strength as a performance measure and dexterity as a performance measure.

Strength As Dependent Variable

The data on grip strength and pinch strength was subjected to an analysis of variance (ANOVA); table II shows the ANOVA summary.

Table II. ANOVA Summary on Grip and Pinch Strength

DEP. VAR	GEN	GLV MKE	GLV TYP	PRES	TYP MKE	MKE PRES	TYP PRES	GEN MKE	GEN TYP	GEN PRE
GRIP	***	***	ns	***	**	***	*	ns	***	ns
PINCH	***	***	***	***	ns	nc	*	***	ns	***

nc not calculated; *** $p<.0001$; ** $p<.001$; * $p<.01$

It is seen that all the main factors are significant for pulp pinch strength, while glove type (TMG or no TMG) effect is not significant for grip strength. Female subjects exhibited lower strengths than their male counterparts as shown in table III, which shows the average strength across the three pairs of gloves tested.

Table III. Gender Effect on Grip and Pinch Strengths

STRENGTH	MALE	FEMALE
GRIP	58.84 (18.57) lbs	36.93 (11.75) lbs
PINCH	17.94 (5.30) lbs	13.08 (2.79) lbs

(Standard deviation in parenthesis)

Grip Strength Results

Figure 3 shows the plot of the gender effect on grip strength. It is seen that the male subjects demonstrated much higher strength capabilities than the female subjects. This result is consistent with the general findings that female strength capabilities are about 60-70% of male capabilities. Figure 4 shows the plot of glove effect on grip strength. Compared to bare-hand capabilities, there is a 50% reduction in grip strength when gloves are donned. Figure 5 shows the plot of pressure effect on grip strength. As expected, performance reduces with increasing pressure differential. Strength reductions are considerable from bare-handed to gloved condition. It appears that there are two levels of performance decrements with pressure: performance at 3.2 and 4.3 psi look similar, while performance at 6.3 and 8.3 psi appear similar, and worse than other pressure differentials.

Figure 6 shows the plot of the gender*TMG interaction on grip strength. It is interesting to note that the male subjects experienced improved grip strength after donning TMG, while the female subjects experienced reduced grip strength. With TMG, there are two counteracting issues: the increased thickness, which should reduce tactility and thereby reduce strength; and better surface texture, which facilitates gripping. Further, size and extent of fit may be causing this result. Figure 7 shows the plot of glove*TMG interaction on grip strength. Glove C seems to stand out from the other two. TMG seems to reduce strength on glove C, while the opposite effect is observed on gloves A and B. Figure 8 shows the plot of the glove*pressure interaction on grip strength. It is noted that, among the three gloves tested here, glove B seems to have the least reduction in grip strength with pressure differential. Figure 9 shows the plot of pressure*TMG interaction on grip strength. It is observed that, at higher pressure differentials (6.3 and 8.3 psi), subjects demonstrated greater grip strength capabilities without TMG.

Pinch Strength Results

Figure 10 shows the plot of the glove effect on pinch strength; the strength capabilities do not appear to reduce much with gloves. Figure 11 shows the TMG effect on pinch strength. Again, strength appears to be reduced with TMG. Figure 12 shows the pressure effect on pinch strength. As with glove effect, the reduction in pinch strength with pressure, though statistically significant, is not much. Figure 13 shows the plot of gender*glove interaction on pinch strength. Male subjects appear to demonstrate the greatest pinch strength with glove C. The plot of pressure*gender interaction on pinch strength is shown in figure 14. Again, male subjects seem to show the greatest pinch strength at 3.2 psi. Figure 15 shows the plot of the pressure*TMG interaction. Without TMG, there seems to be a gradual reduction in pinch strength with increasing pressure, while with TMG the pinch strength appears to increase in the 8.3 psi condition. Overall, it should be noted that most of the curves depicting effects on pinch strength are flatter as compared to the corresponding effects on grip strength.

Dexterity Measures As Dependent Variable

The ANOVA summary is given in table IV. It is seen that gender and subject effects are significant for all the dependent measures.

Table IV. Summary of ANOVA for the Dexterity Measures

EFFECTS	SMALL NUT AND BOLT	MEDIUM NUT AND BOLT	LARGE NUT AND BOLT	SMALL KNOT	MEDIUM KNOT	LARGE KNOT	2PD
GENDER	***	***	***	***	***	***	***
SUBJECT	***	***	***	***	***	***	***
GLOVE	ns	***	ns	ns	ns	ns	ns
TMG	ns	***	ns	ns	***	***	***
PSI	***	***	***	***	***	***	ns
GEN*GLOVE	ns	***	ns	**	*	**	*
GEN*TMG	*	ns	ns	ns	ns	*	**
GEN*PSI	ns	***	ns	**	ns	*	ns
GLOVE*TMG	**	**	ns	*	*	*	ns
GLOVE*PSI	**	ns	ns	**	**	*	ns
TMG*PSI	**	***	ns	*	*	*	ns

Nuts-and-Bolts Assembly Task Results

Figure 16 shows the graph of the gender effect on the assembly time. Female subjects were slower than their male counterparts by as much as 33%. There appears to be a distinct size effect, with the larger-sized nuts and bolts requiring less assembly time. The glove effect on the assembly time is shown in figure 17. It is interesting to note the assembly time increases fivefold with gloves for all the subjects (10.99 sec to 55.36 sec for males, and 18.11 sec to 82.60 sec for females). The size effect seems to be prominent with the gloved hand, with no differences in assembly time for the three sizes with the bare hand. Figure 18 shows the plot of the pressure effect on the assembly time. There is a steady increase in assembly time with increasing pressure. The average time at 8.3 psi is nearly 240% more than at 0 psi, which itself is much more than the bare-handed assembly time (115 sec, 50 sec, and 15.5 sec, respectively). The size effect appears to be consistent across all the pressure levels tested. Figure 19 shows the gender*TMG interaction on the small nuts-and-bolts assembly time. Donning TMG appears to improve performance for the male subjects while the opposite seems to be true for the female subjects. Figure 20 shows the plot of glove*TMG interaction on the small nuts-and-bolts assembly time. Glove B appears to produce the best interaction. For gloves A and C, the performance seems to become worse with TMG. Figure 21 shows the graph of pressure*glove interaction on the small nuts-and-bolts assembly time. Glove A appears to have the best results at 8.3 psi, while glove B appears best at 4.3 psi. The TMG*pressure interaction on the small nuts-and-bolts assembly time is shown in figure 22. Contrary to expectations, the "no TMG" condition seems to be better than the "TMG" condition for all pressures except at 8.3 psi. The TMG effect on the medium nuts-and-bolts assembly time is shown in figure 23. Performance improved with TMG (76.22 sec to 66.57 sec).

Knot-Tying Task Results

Figure 24 shows the plot of the gender effect on the mean knot-tying time. The female subjects were slower than the male subjects. A size effect is also seen with longer times for smaller-sized string. Figure 25 shows the glove effect on the mean knot-tying time. Bare-handed performance is far quicker than gloved performance. The performances with gloves appear to be comparable with each other, as does the size effect. Figure 26 shows the pressure effect on the mean knot-tying time. The performance appears to degenerate with increasing pressure. The performance decrement looks consistent across all three sizes of string tested here. The TMG effect on the mean knot-tying time for the medium and large strings is shown in figure 27. Figure 28 shows the plot of the gender*glove interaction for the mean small knot-tying time. The bare-handed performance was significantly quicker than the gloved performance. It is interesting to note that female subjects were quickest with glove A, while the male subjects were quickest on gloves B and C. Figure 29 shows the plot of the gender*pressure interaction on the mean small knot-tying time. The performance degenerated with increasing pressure. The improvement in performance at 4.3 psi for the male subjects, and at 8.3 psi for the female subjects, may have been due to an artifact of sample size, and defies any other explanation. It is seen from figure 30 that the TMG improved performance at 6.3 and 8.3 psi, while at lower pressures the "no TMG" condition resulted in shorter knot-tying time. Figure 31 shows the plot of the glove*pressure interaction on the mean knot-tying time. Glove C appears to be the worst at 4.3 psi, while gloves A and B are comparable at 8.3 psi. Figure 32 shows the plot of the glove*pressure interaction on the mean medium knot-tying time. Glove A appears to be the best among the three gloves tested here. The glove*TMG interaction is shown in figure 33. The TMG of glove C appears to be worse than that of the other two gloves. Figure 34 shows the plot of the TMG*pressure interaction. Glove*pressure interaction on the mean large knot-tying time is shown in figure 35. Glove A appears to be the best at all pressures. The glove*TMG interaction is shown in figure 36. Again, Glove B seems to have the best TMG. The gender*pressure interaction is shown in figure 37. The gender*TMG interaction plot for the mean large knot-tying time is shown in figure 38.

Two-Point Discrimination Test Results

Figure 39 shows the plot of the gender effect on the 2PD distance. Female subjects had a longer discrimination distance than male subjects. Figure 40 shows the TMG effect on 2PD distance. The discrimination distance with TMG was longer than otherwise. An interesting finding of this investigation is that, while tactile performance decreased with TMG, performance in knot-tying and nuts-and-bolts assembly tasks improved with TMG. Either the 2PD test was inadequate, or there is something more to the relationship between tactility and dexterity than what was being measured through a 2PD test here.

Analysis of Covariance

Hand anthropometric measures of subjects were recorded in order to determine if a size effect existed. Included in this were hand length, hand breadth, distance of all the fingers from the crotch, and upper arm lengths. Analyses of covariance indicated that upper arm length, hand length, and hand breadth were significant ($p<.0001$), while the finger lengths were not significant. This substantiates the fact that the glove/hand fit, which was not controlled in this study, is an important parameter that could influence performance.

Discussion and Conclusion

The gender effect was perhaps the most consistent finding of this experiment. Female subjects tended to perform slower, and showed lower strength capabilities. Table 5 shows the mean time for male and female subjects for the different dependent measures.

Table V. Mean Time for Males and Females

PERFORMANCE MEASURE	MEAN TIME FOR MALES	MEAN TIME FOR FEMALES
Small Nuts-and-Bolts Assy Time	65.93 sec	94.45 sec
Medium Nuts-and-Bolts Assy Time	54.52 sec	83.13 sec
Large Nuts-and-Bolts Assy Time	45.63 sec	70.24 sec
Small Knot-Tying Time	86.91 sec	117.28 sec
Medium Knot-Tying Time	80.26 sec	104.87 sec
Large Knot-Tying Time	59.24 sec	81.91 sec
Two-Point Discrimination Length	9.03	11.87

It is seen from the above table that the gender difference is present in all the performance measurements, with the females performing about 30% slower than the males. The fit of the glove to the hand, which was not controlled in this experiment, may have caused the gender difference.

The next major finding of this experiment is that both pressure and glove reduce performance. It is also apparent that gender differences are more defined based on both bare-handed and gloved conditions at zero psi differential than at other conditions. These findings are consistent with those reported by O'Hara et al (1988) and others (Wang et al 1987; Cochran et al 1986). With gloves, there is an apparent increase in grip span, and an earlier pressing of fingers with each other. The former should increase the grip strength, while the latter should reduce the grip strength. It appears that the effects of increase in grip span with gloves is somewhat counteracted by the reduction in the inter-digital movements and range of motion when gloves are donned, resulting in net reduction in performance. Some of the observed gender differences may also have been due to lack of fit between hand and glove. Lack of glove effect on pinch strength is consistent with those reported by Hallbeck and McMullin (1991). As the points of application of pinch force are at the tips of digits 1, 2 and 3, a glove effect was not expected. In fact, gloves may even increase pinch force due to the extra cushioning provided at the point of contact.

The reduced performance on dexterity measurements with gloves is perhaps due to reduced range of motion and tactile sensitivity. With gloves, one would expect reduced inter-digital movements, range of motion, and tactile sensitivity. These were perhaps causing the observed performance decrements. Although the level of performance with gloves was reduced as compared to a bare-handed condition, the respective performances among the three gloves tested were comparable. Once again, it is interesting to note that, while tactile performance decreased with TMG, performance in knot-tying and nuts-and-bolts assembly tasks improved with TMG. Either the 2PD test was inadequate, or there is something more to the relationship between tactility and dexterity than what was being measured through a 2PD test here.

One of the objectives of this experiment was to perform a comparison of the three gloves, with and without TMG. An explanation for TMG is in order here. Space shuttle gloves have two components, an inner glove which has all the hardware for pressurization, and an outer glove to protect the wearer from the harsh thermal micrometeoroid environment of outer space. The outer glove is called TMG, and was one of the factors investigated here. A possible glove*TMG interaction can have some interesting implications for the designers. The interaction of the TMG of glove B appears to be the best, while that of glove C is the worst. The results suggest that in the case of glove C, TMG does not change the performance level, while it does offer the needed protection. However, the TMG of gloves A and B, in addition to providing protection against the environment, seems to improve performance as well. Overall, glove B seems to be the most preferable. Its TMG shows the best performance improvement, and it has the best strength performance at all the pressure differentials. Its dexterity performance, however, was comparable to that of glove A, and much better than glove C. Glove B has a metacarpal joint as part of its design feature. Perhaps it is this difference that is causing it to perform best. More investigation is needed on this issue.

There were some other interesting interactions as well in this experiment. Male subjects' performance improved in the order A, B, and C, while female subjects' performance improved in the opposite order, C, B, and A.

The important findings of this research are outlined below:

1. Females demonstrated lower strength capabilities than their male counterparts (table 3 and figure 4).

2. Basic hand grip strength capabilities are reduced by more than 50% when gloves are donned (figure 5).

3. Pressure differentials reduce grip strength further. There is a large drop in capabilities when pressure differential changes from 0 to 3.2 psi, and there is a second, less steep, drop when the pressure differential changes from 3.2 psi to 8.3 psi. (figure 6).

4. There appears to be no corresponding effect on pinch strength based on either glove configuration factors or pressure differential factors (figures 11 and 13).

5. Based on performance characteristics, the TMG configuration of gloves A and B appears to be better than that of glove C. Glove B appears to be the best from a strength viewpoint (figures 8 and 9).

6. Females demonstrated lower capabilities in both the nuts-and-bolts assembly task and in the knot-tying task (figures 17 and 25).

7. As compared to bare-handed performance, gloved performance was observed to be around 4-to-6 times slower in the nuts-and-bolts assembly task and in the knot-tying task (figures 18 and 26).

8. Performance on both the nuts-and-bolts test and the knot-tying test degenerated with increasing pressure differential. As in the case of strength measures, there were two types of performance reductions: a steep reduction between 0 psi and 3.2 psi, and a less steep reduction between 3.2 psi and 8.3 psi (figures 19 and 27).

9. As in the case of strength measures, the TMG of gloves A and B appear to be better than that of glove C (figure 34).

10. Females demonstrated lower tactile sensitivity than males (figure 40). However, the 2PD test as tested here appeared to be unreliable and inadequate.

11. The glove hand fit was not controlled in this study. One pair of gloves in each glove type was used for all the subjects. Some of the gender effect and performance decrements may have been due to lack of glove hand fit.

In summary, it is seen that, with gloves, strength is reduced by nearly 50%. Further performance decrements occur with increasing pressure differential, and TMG effects are not consistent across the three gloves tested. Size was not controlled in this study and may have had an impact on the findings. More research is needed to determine the exact effects of size and glove material on performance. Such data will be invaluable to the designer of hand gloves.

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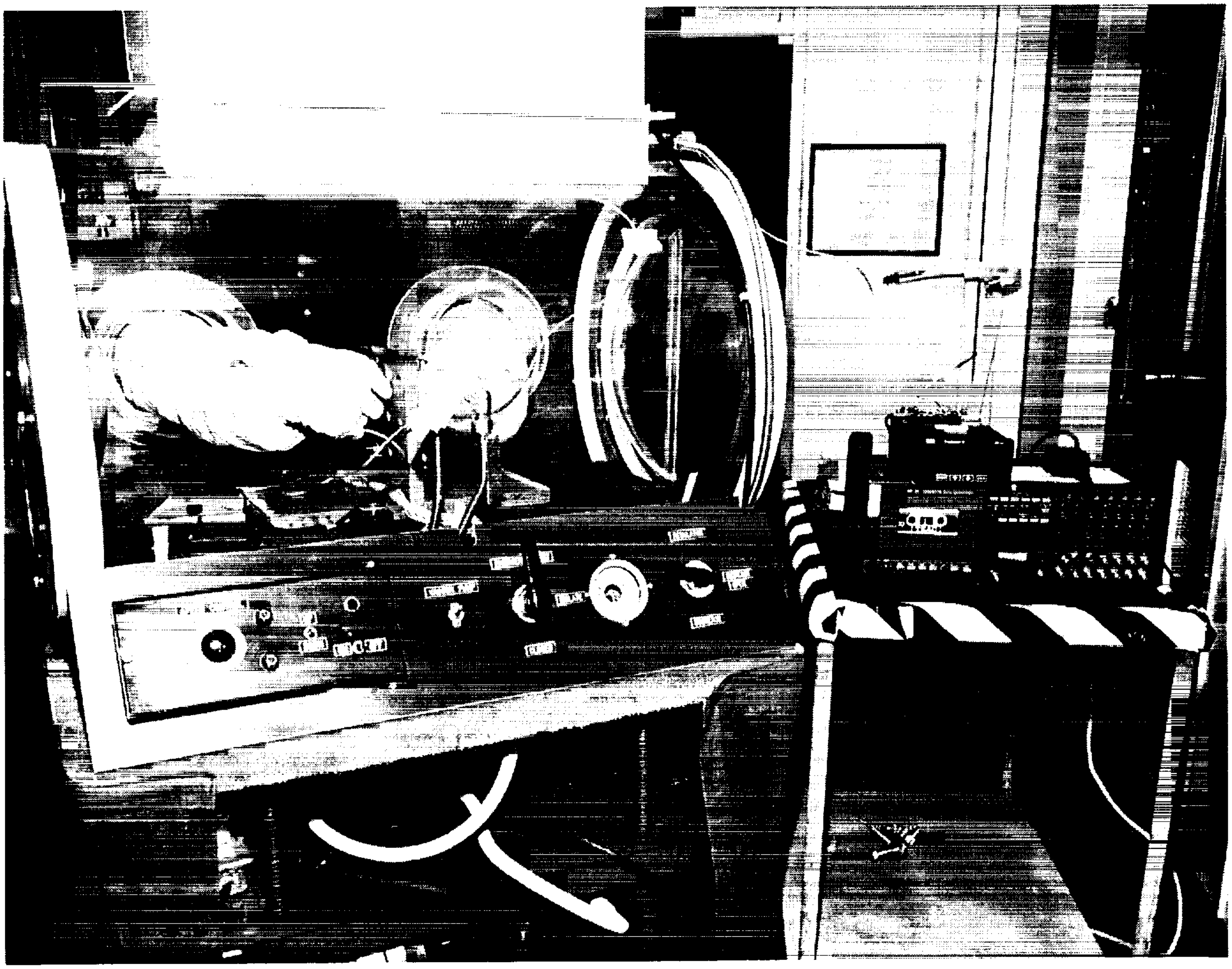

Figure 1. Experimental setup

Figure 2. Different types of gloves test

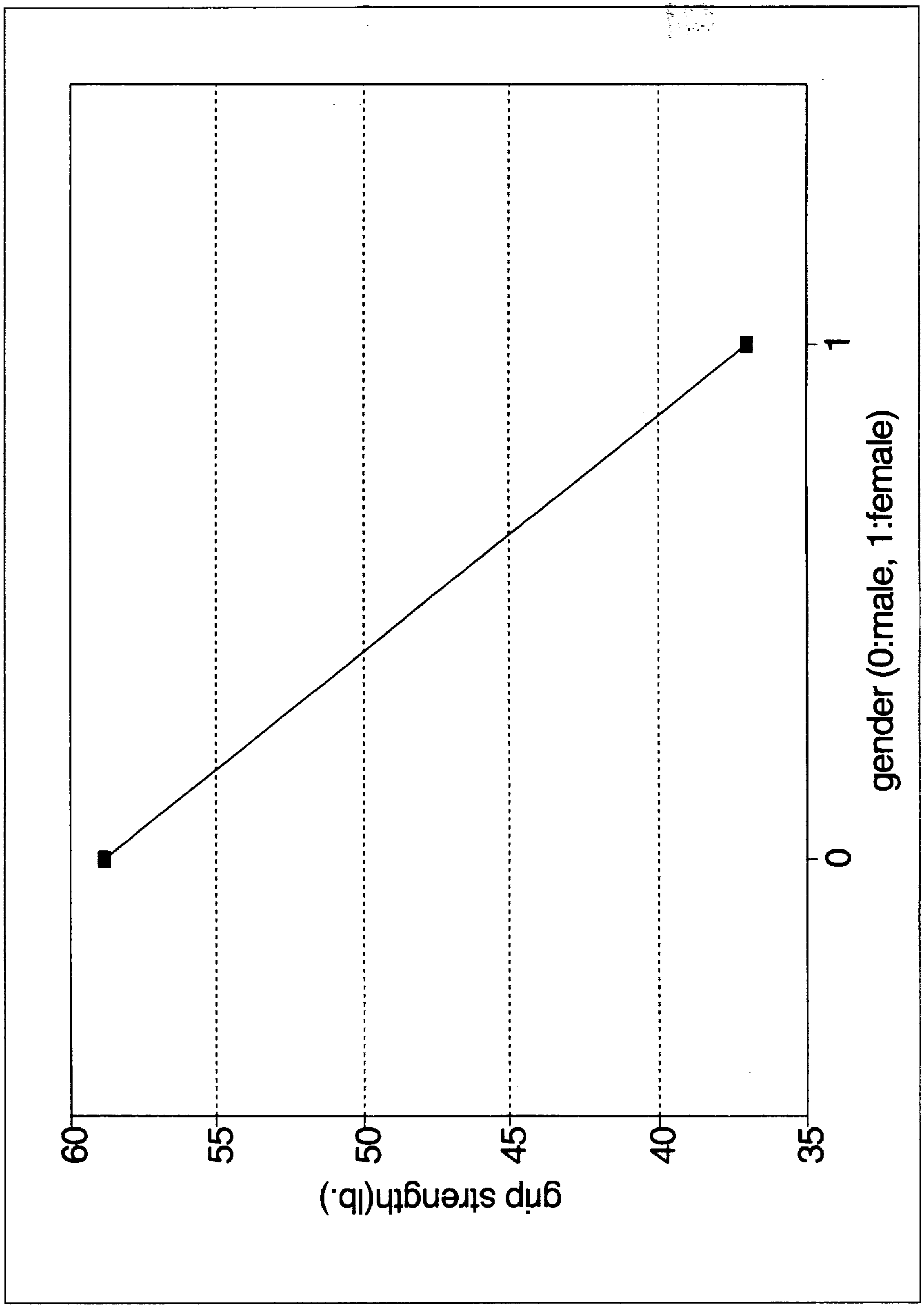

Figure 3. Gender effect on grip strength

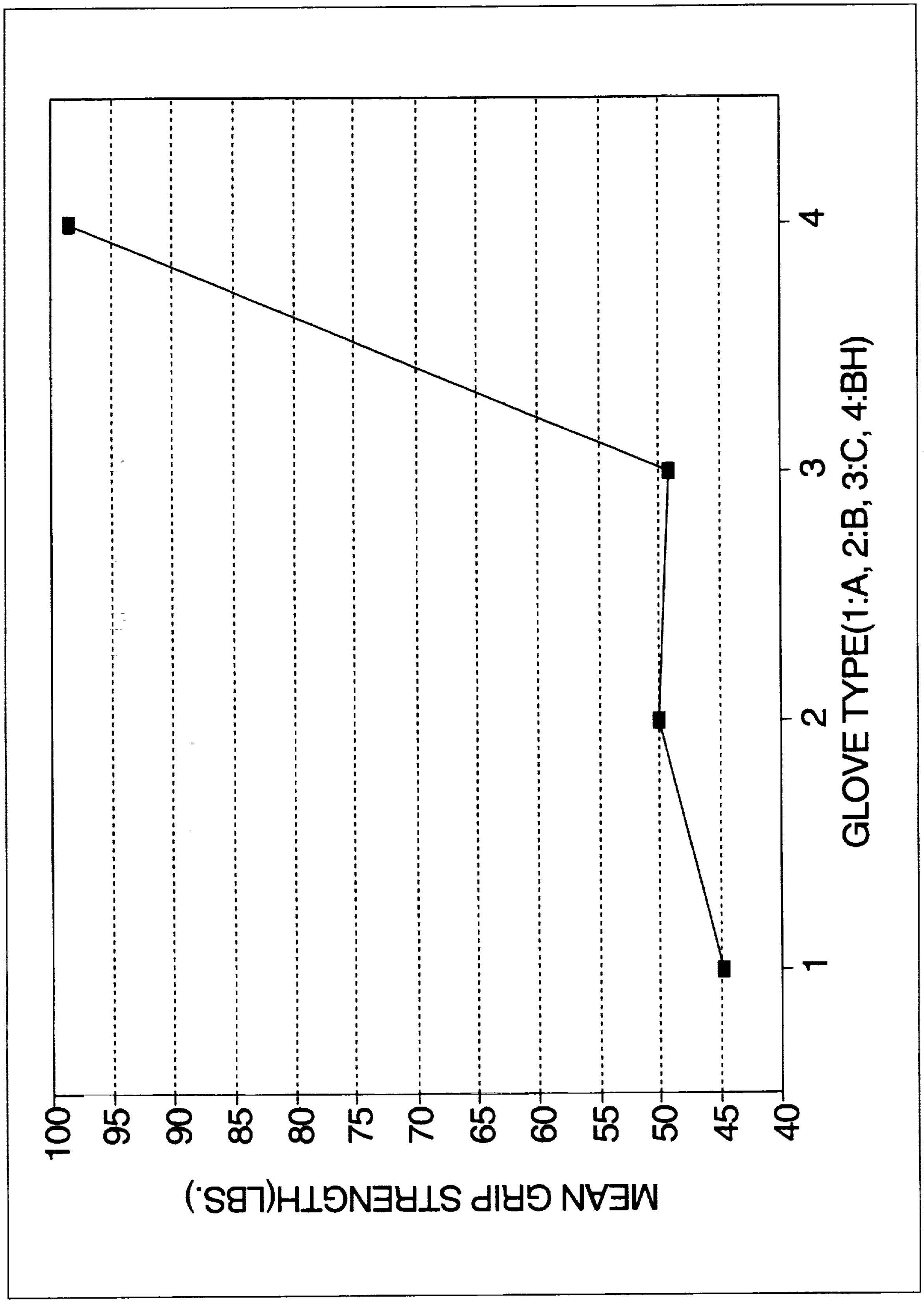

Figure 4. Glove effect on grip strength

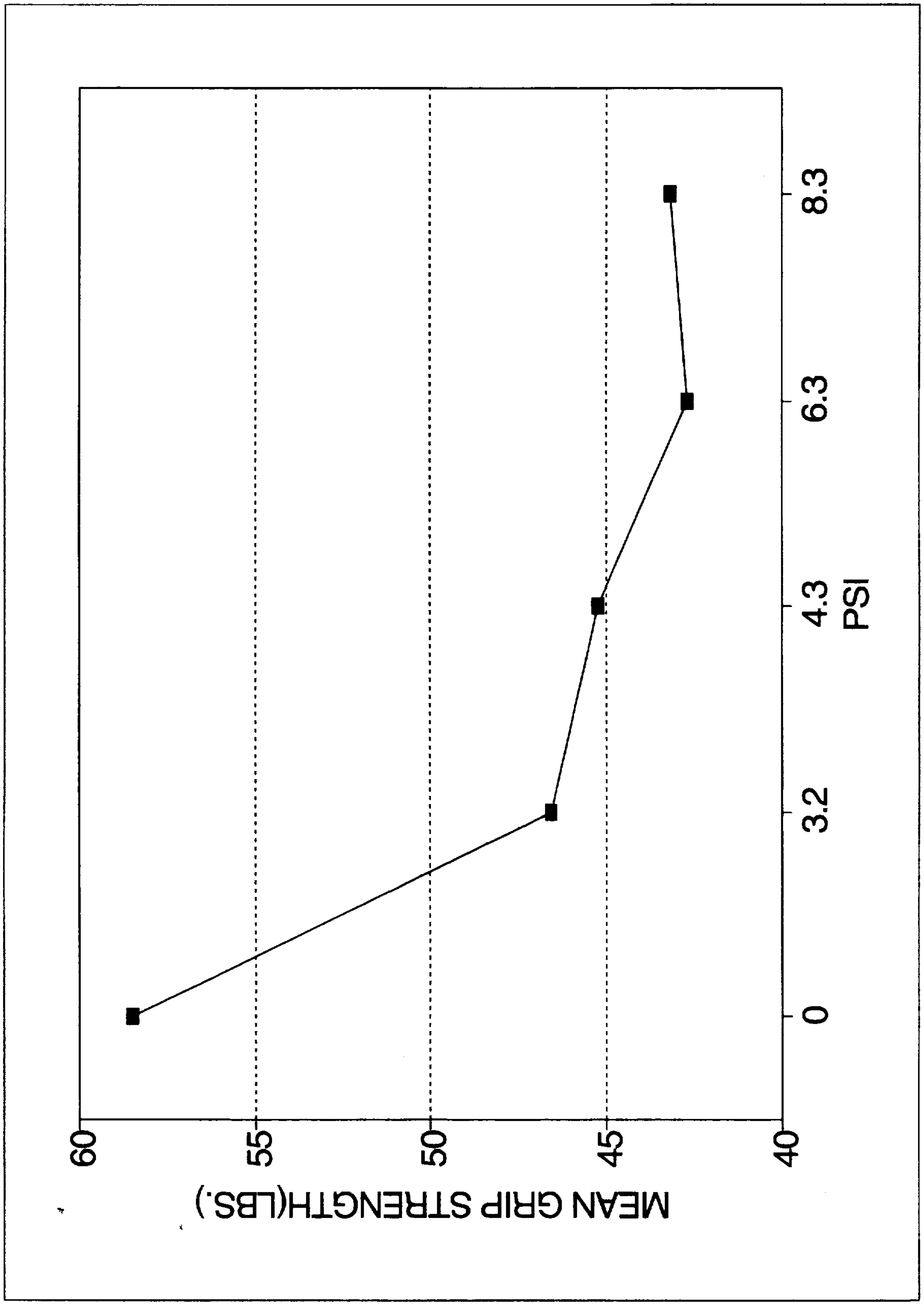

Figure 5. Pressure effect on grip strength

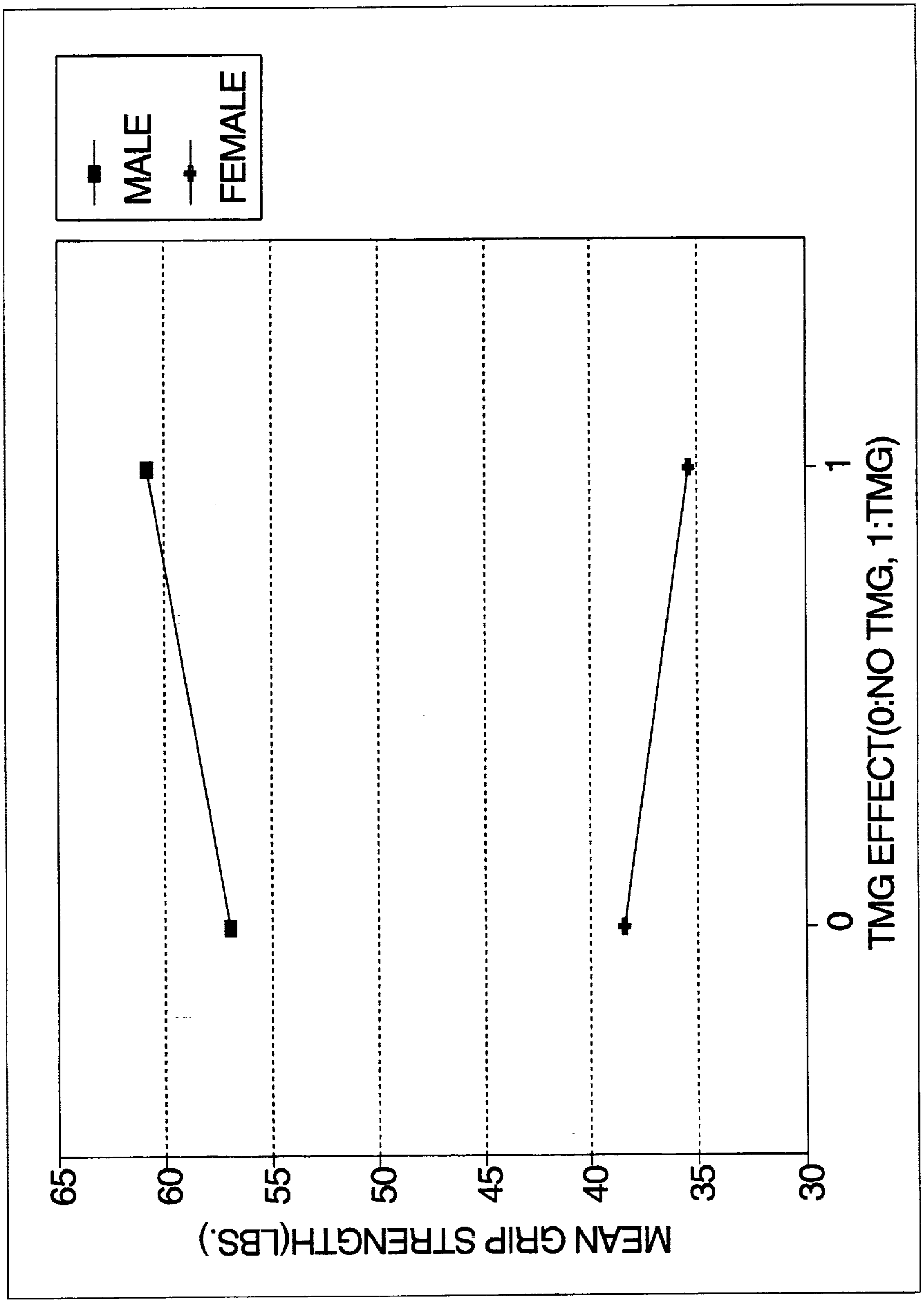

Figure 6. Gender*TMG interaction on grip strength

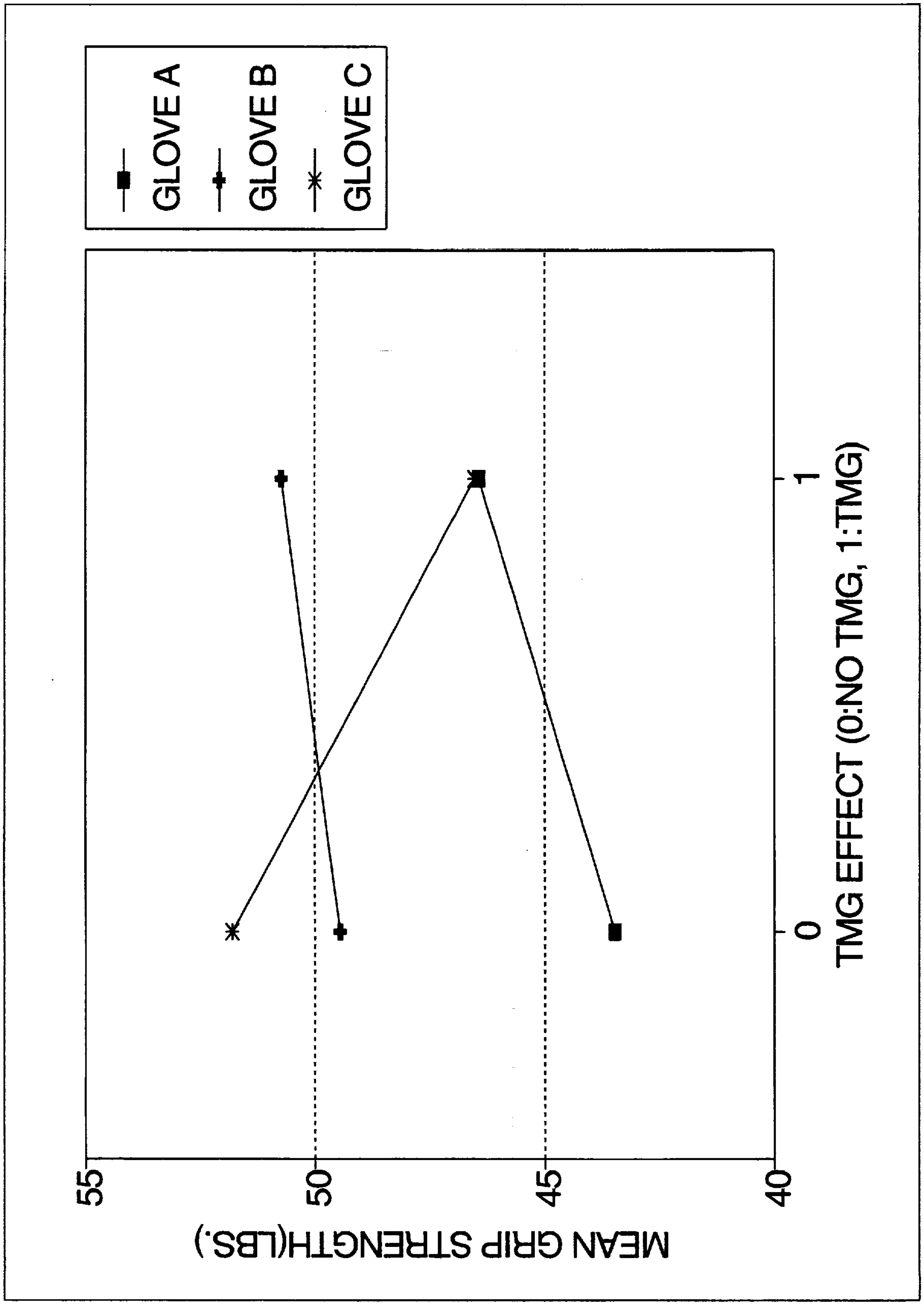

Figure 7. Glove*TMG interaction on grip strength

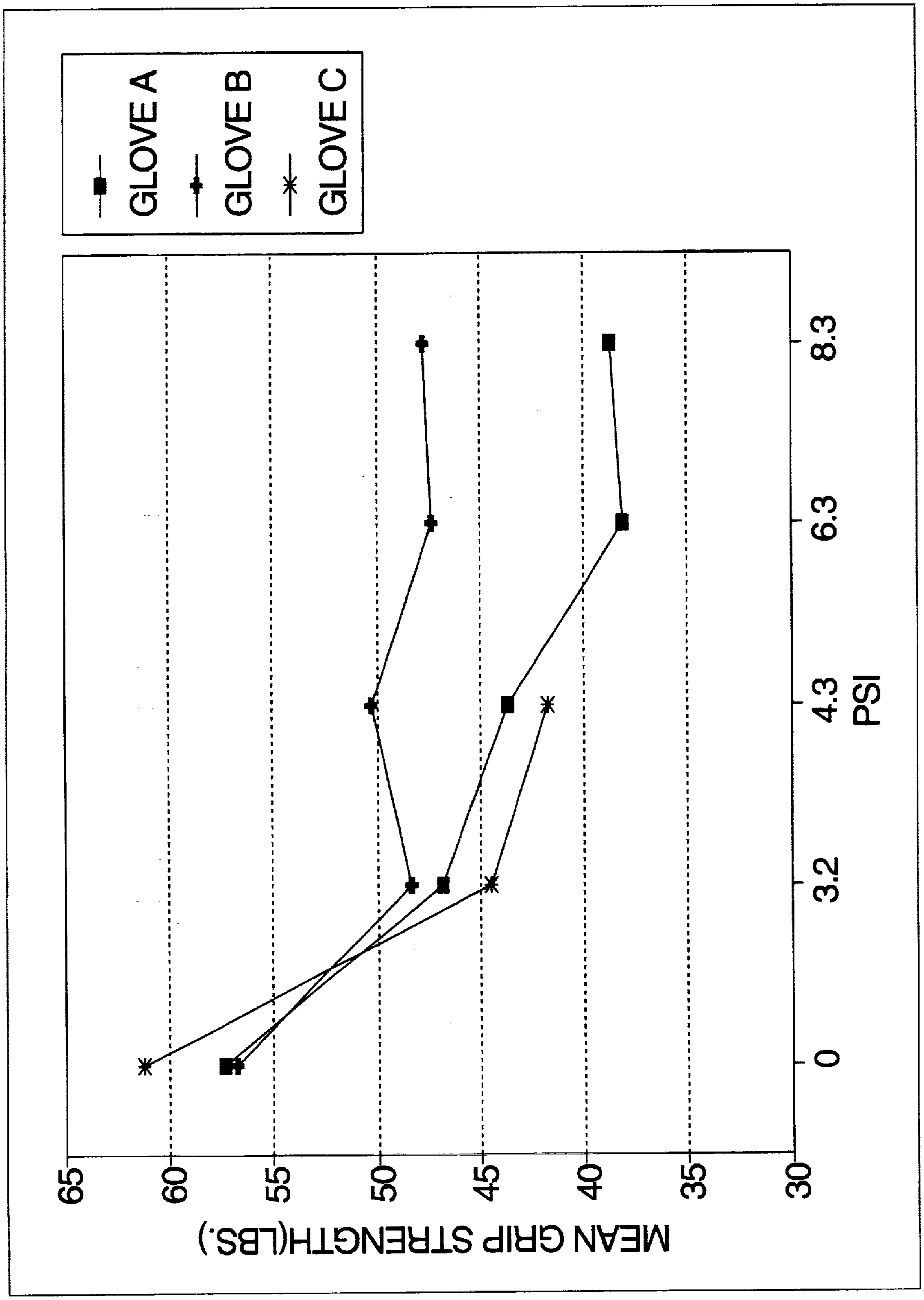

Figure 8. Glove*pressure interaction on grip strength

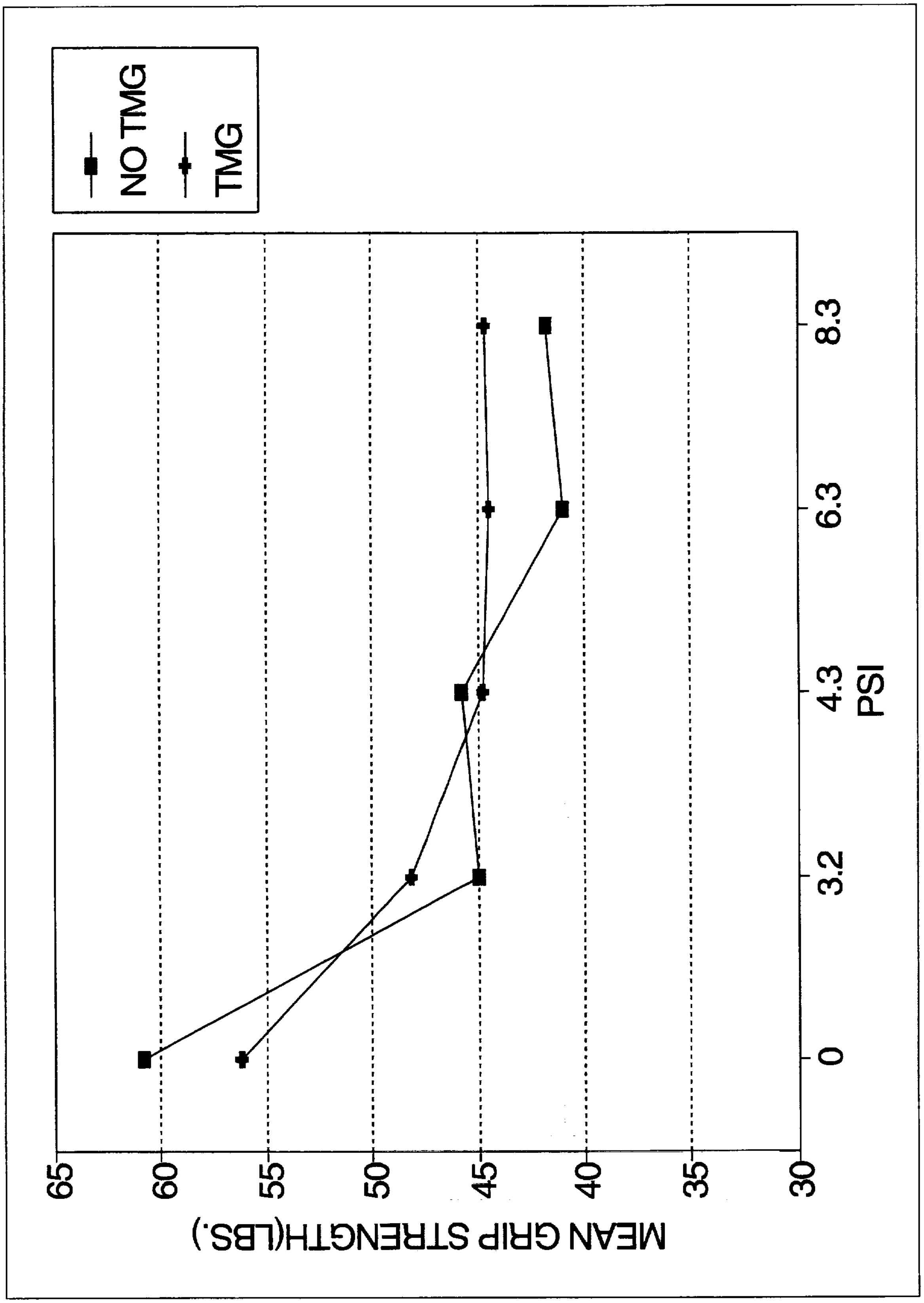

Figure 9. Pressure*TMG interaction on grip strength

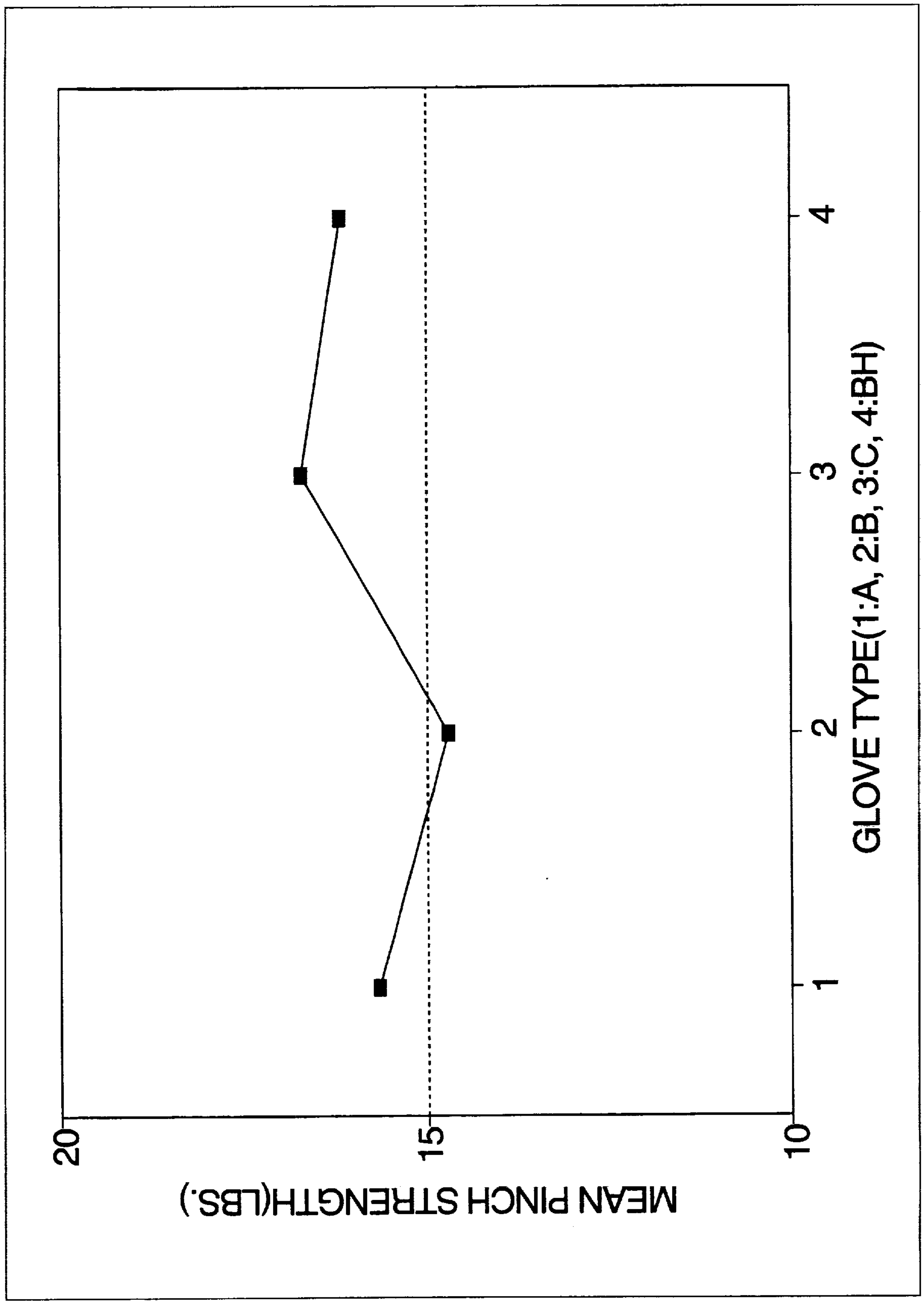

Figure 10. Glove effect on pinch strength

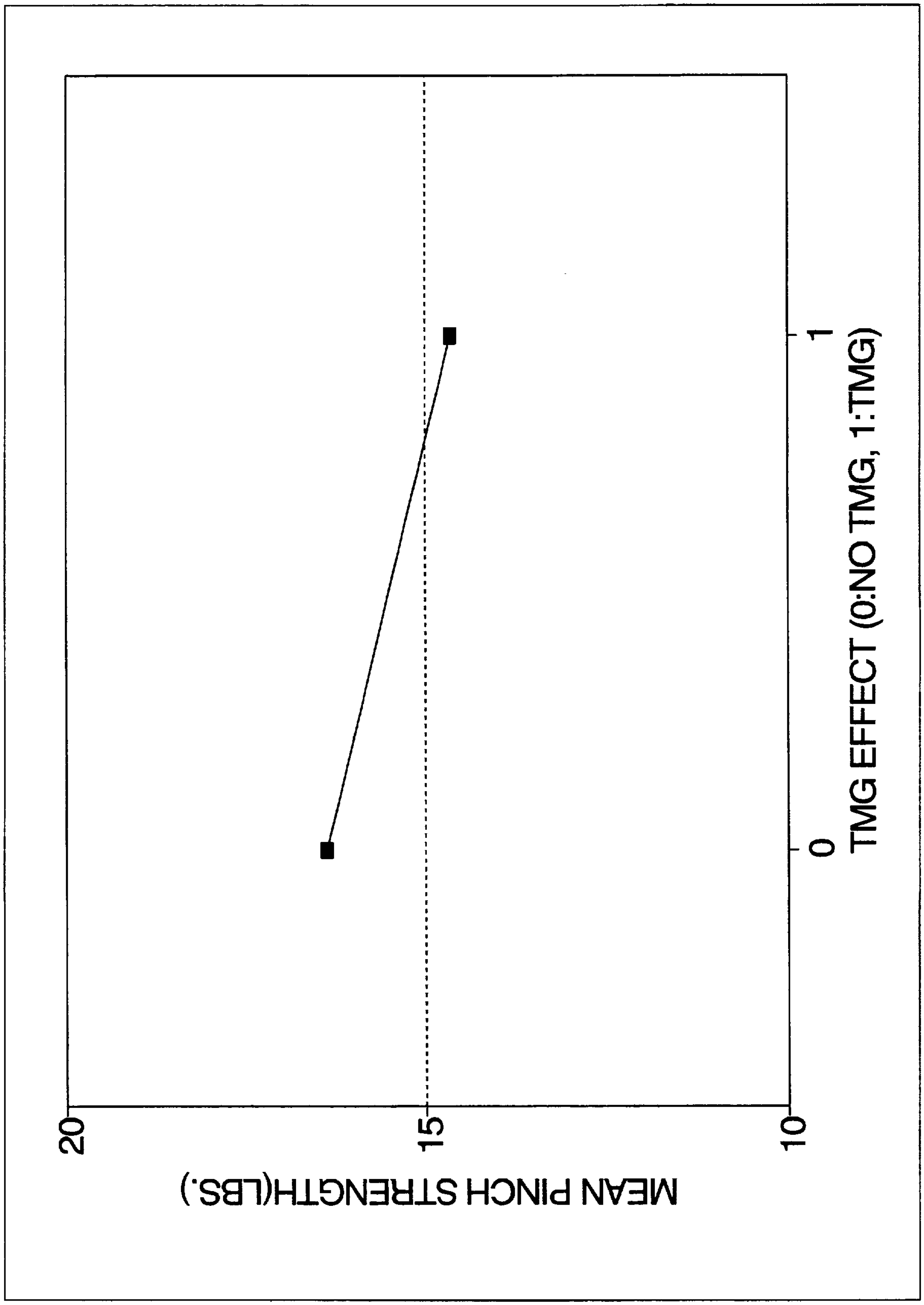

Figure 11. TMG effect on pinch strength

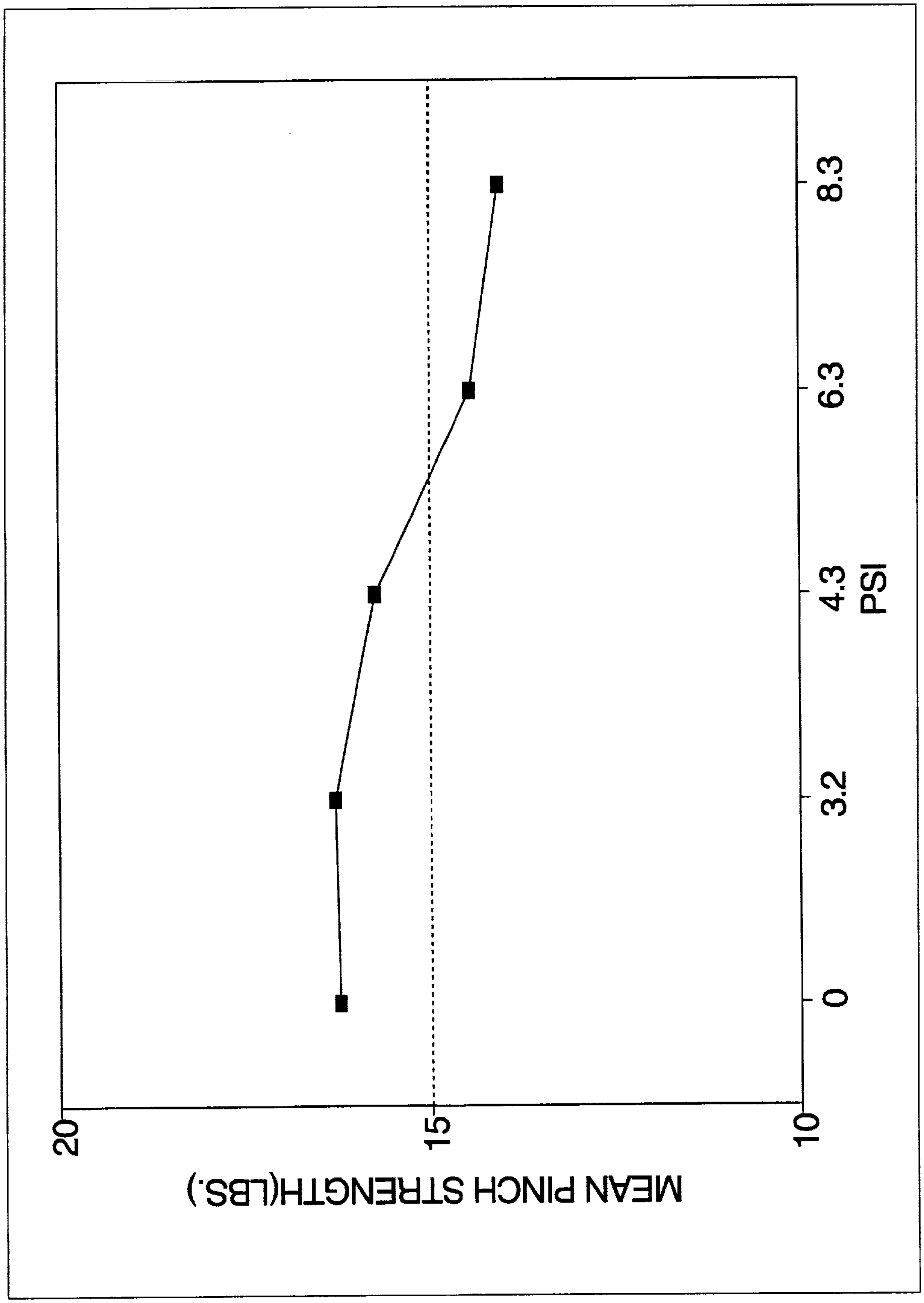

Figure 12. Pressure effect on pinch strength

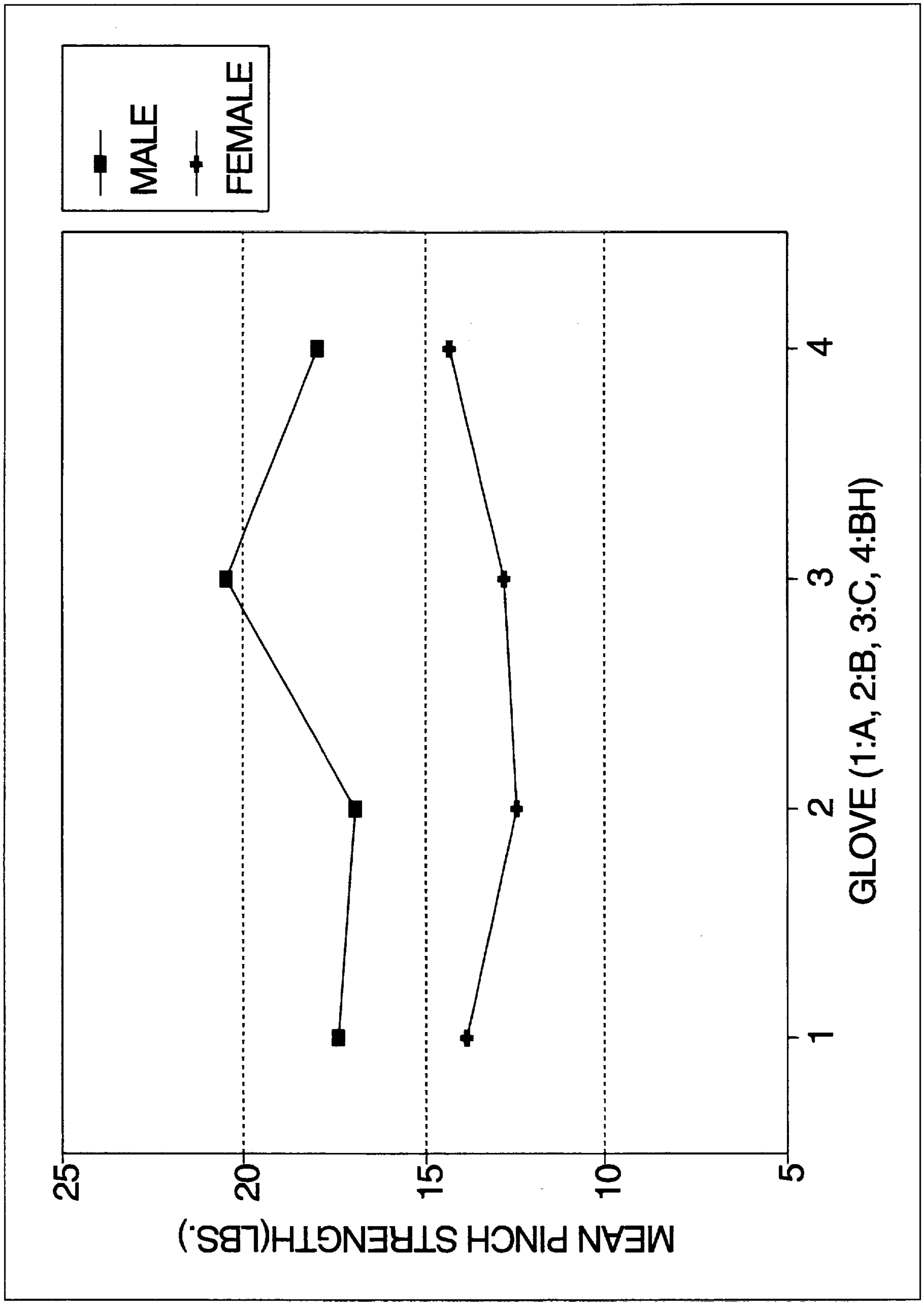

Figure 13. Gender*glove interaction on pinch strength

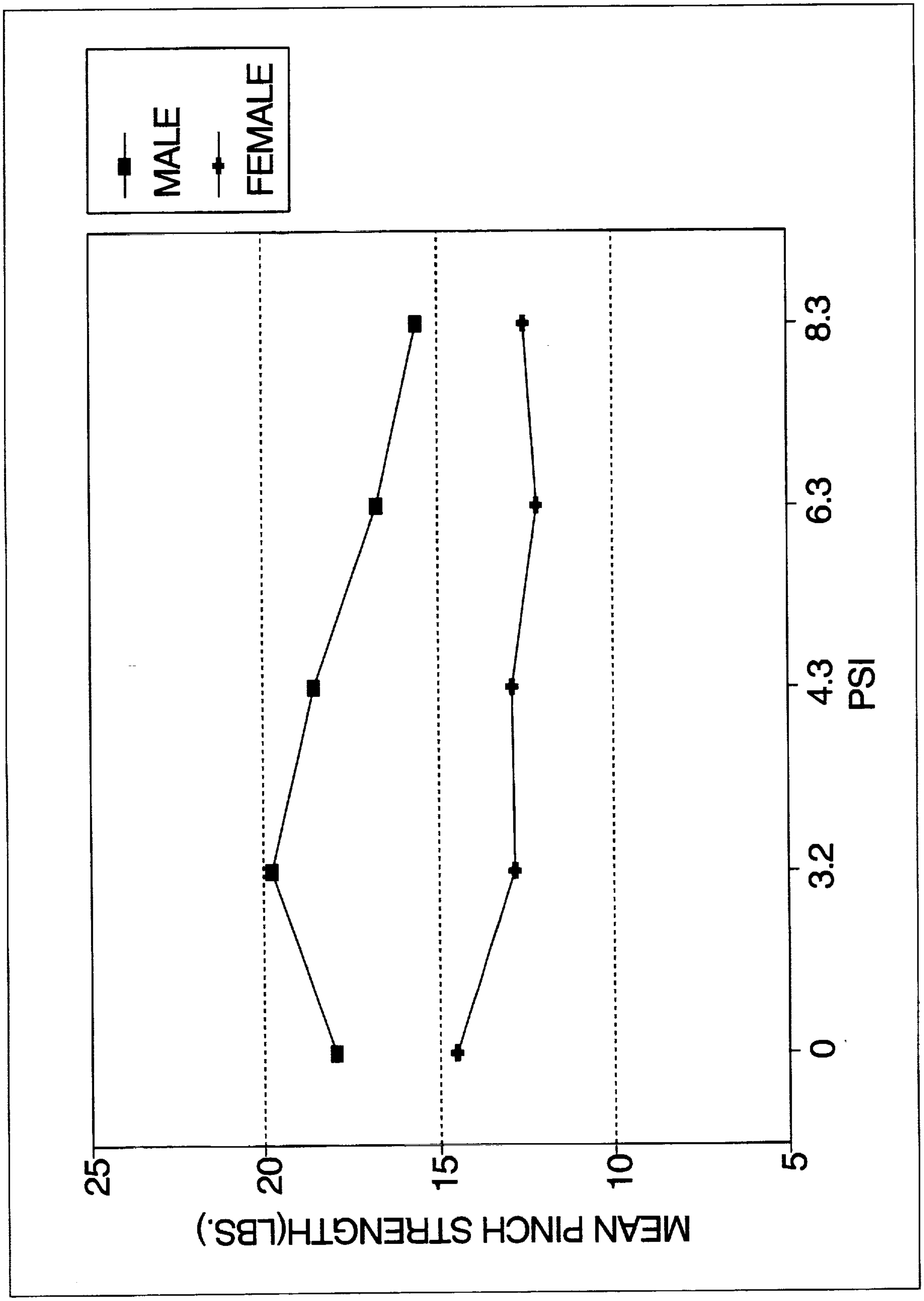

Figure 14. Pressure*gender interaction on pinch strength

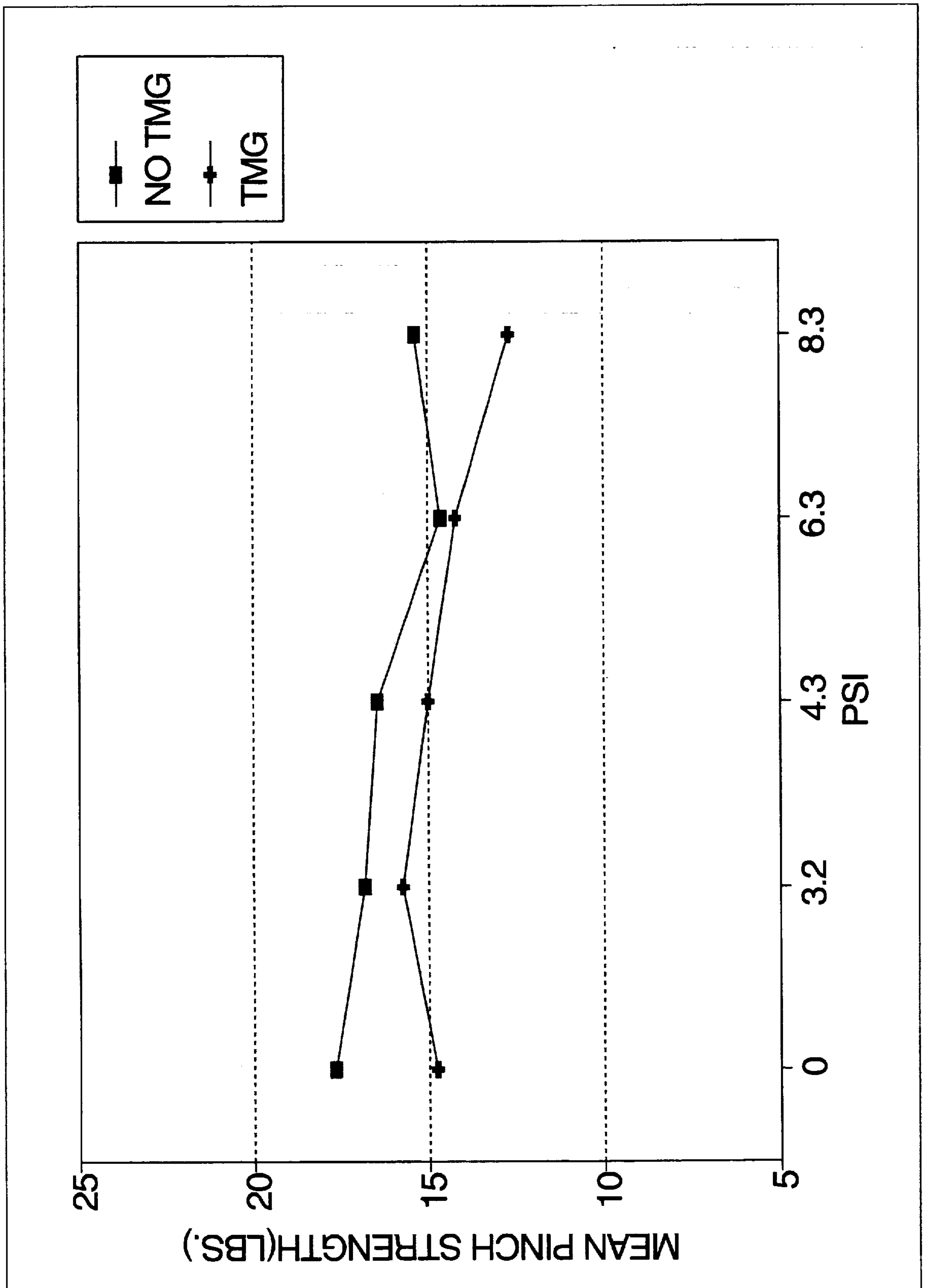

Figure 15. TMG*pressure interaction on pinch strength

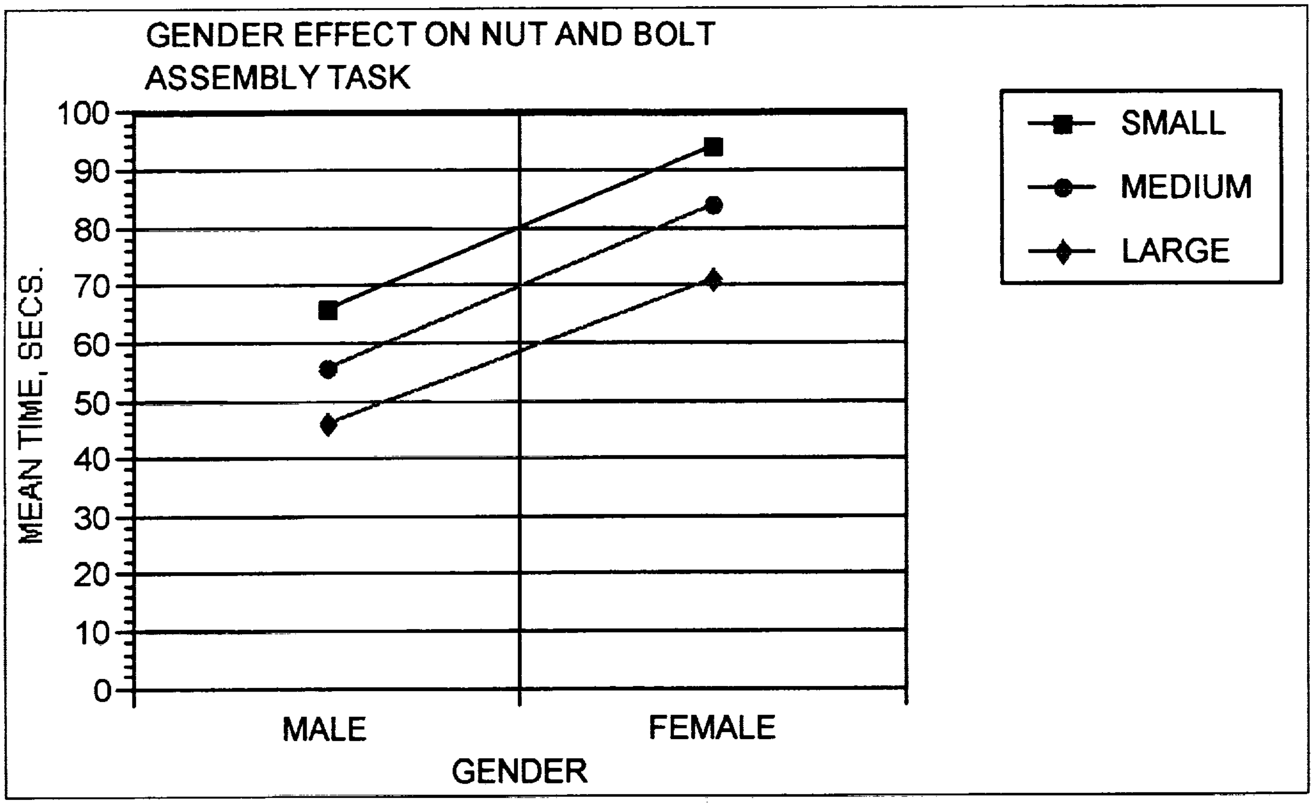

Figure 16. Gender effect on nuts-and-bolts assembly task

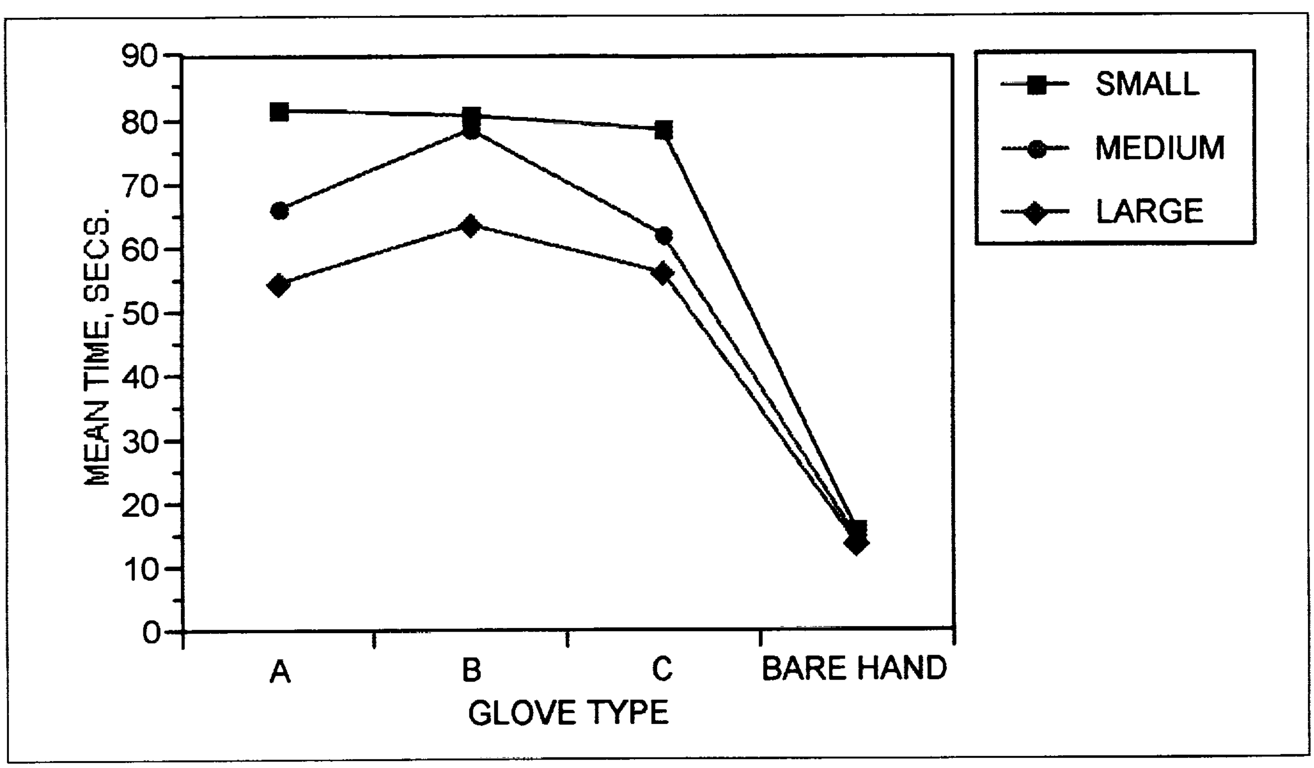

Figure 17. Glove effect on nuts-and-bolts assembly time

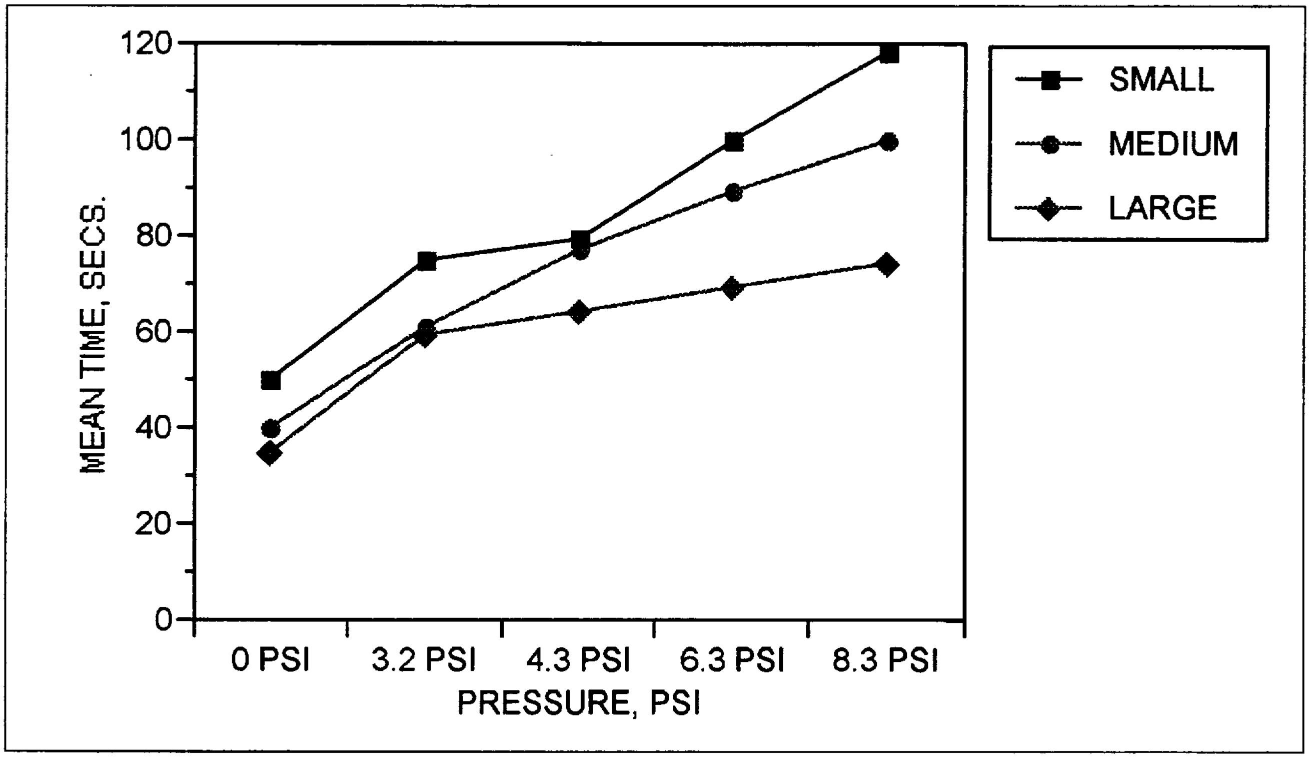

Figure 18. Pressure effect on nuts-and-bolts assembly time

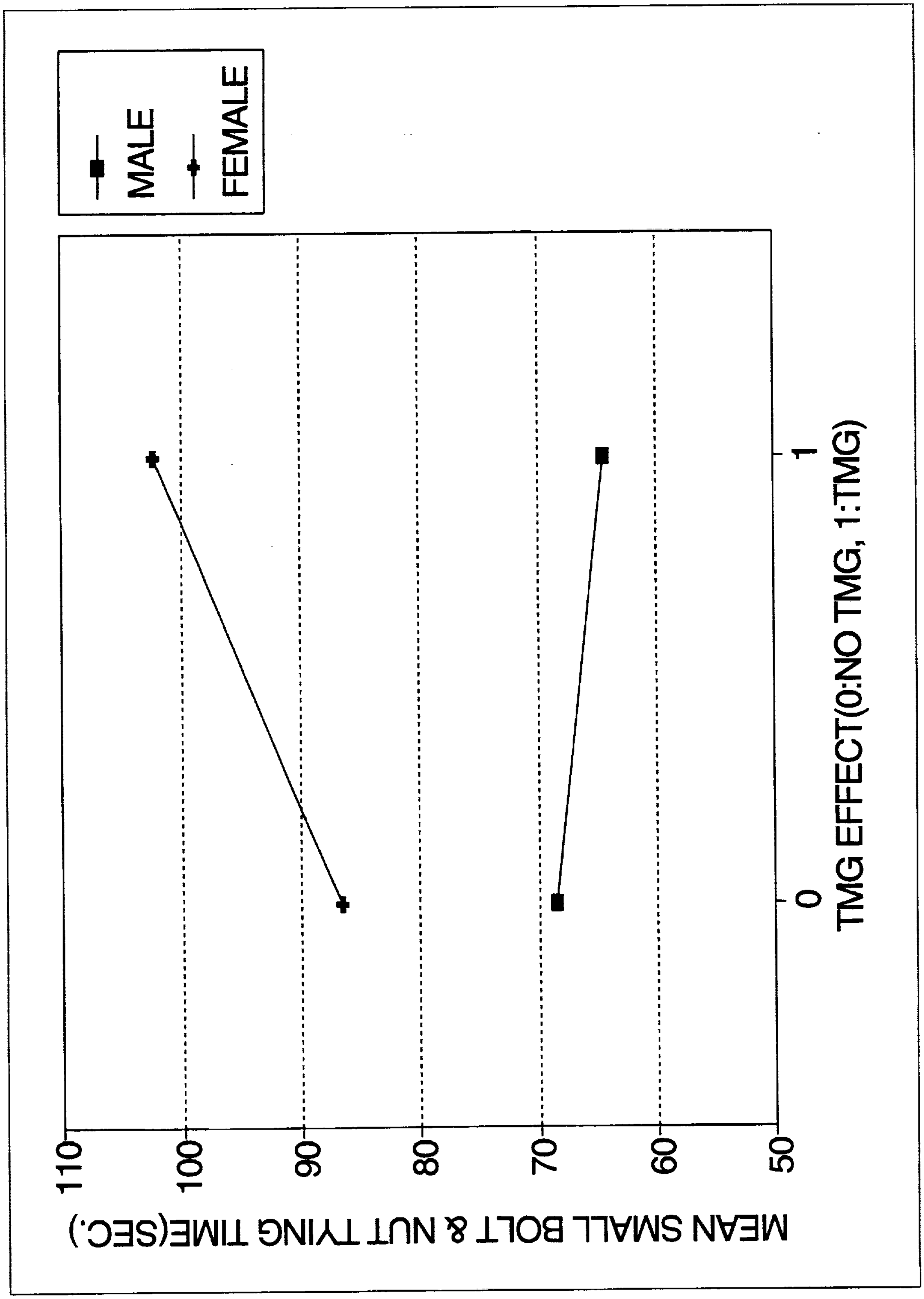

Figure 19. Gender*TMG interaction on small nut-and-bolt assembly time

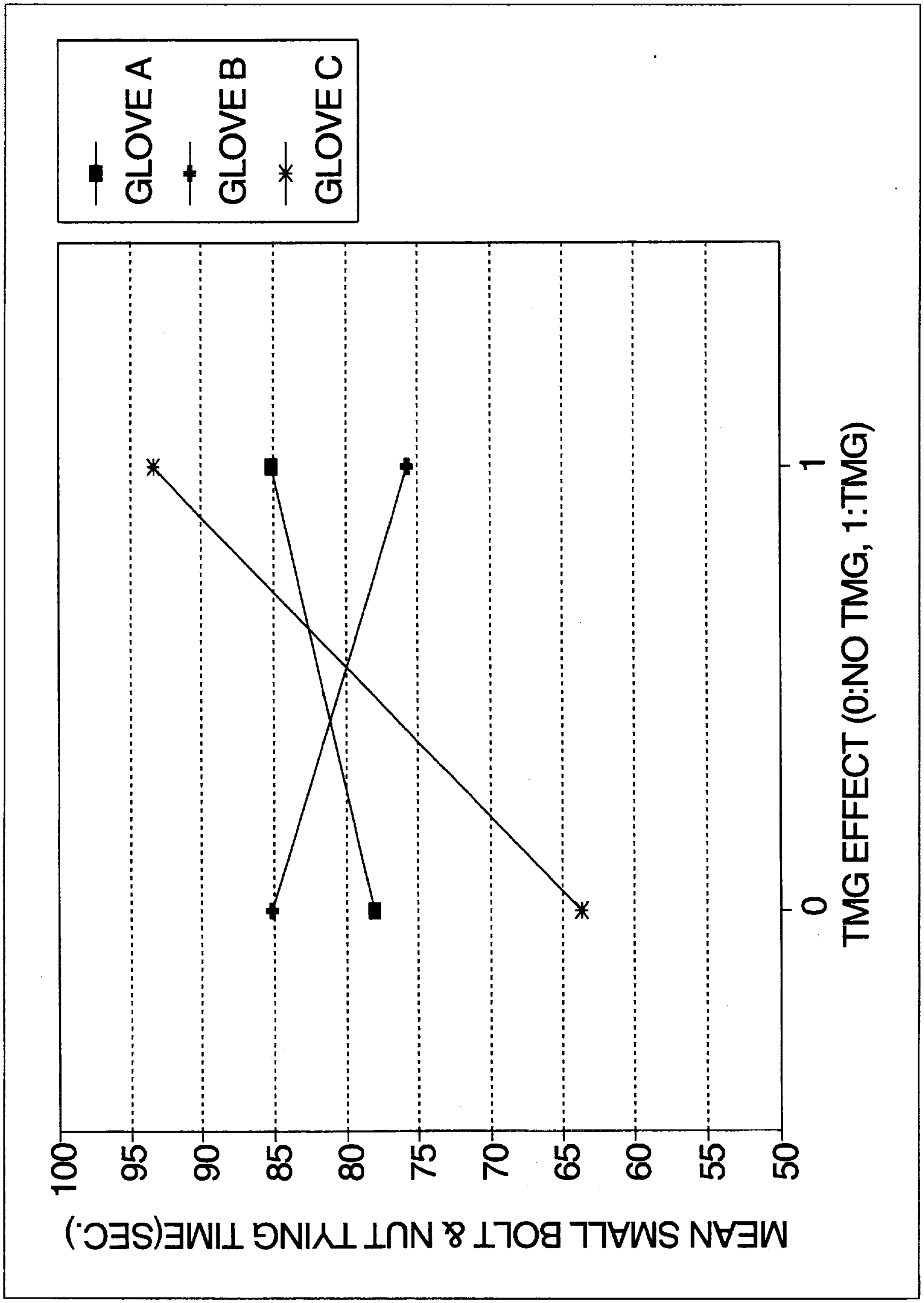

Figure 20. Glove*TMG interaction on small nut-and-bolt assembly time

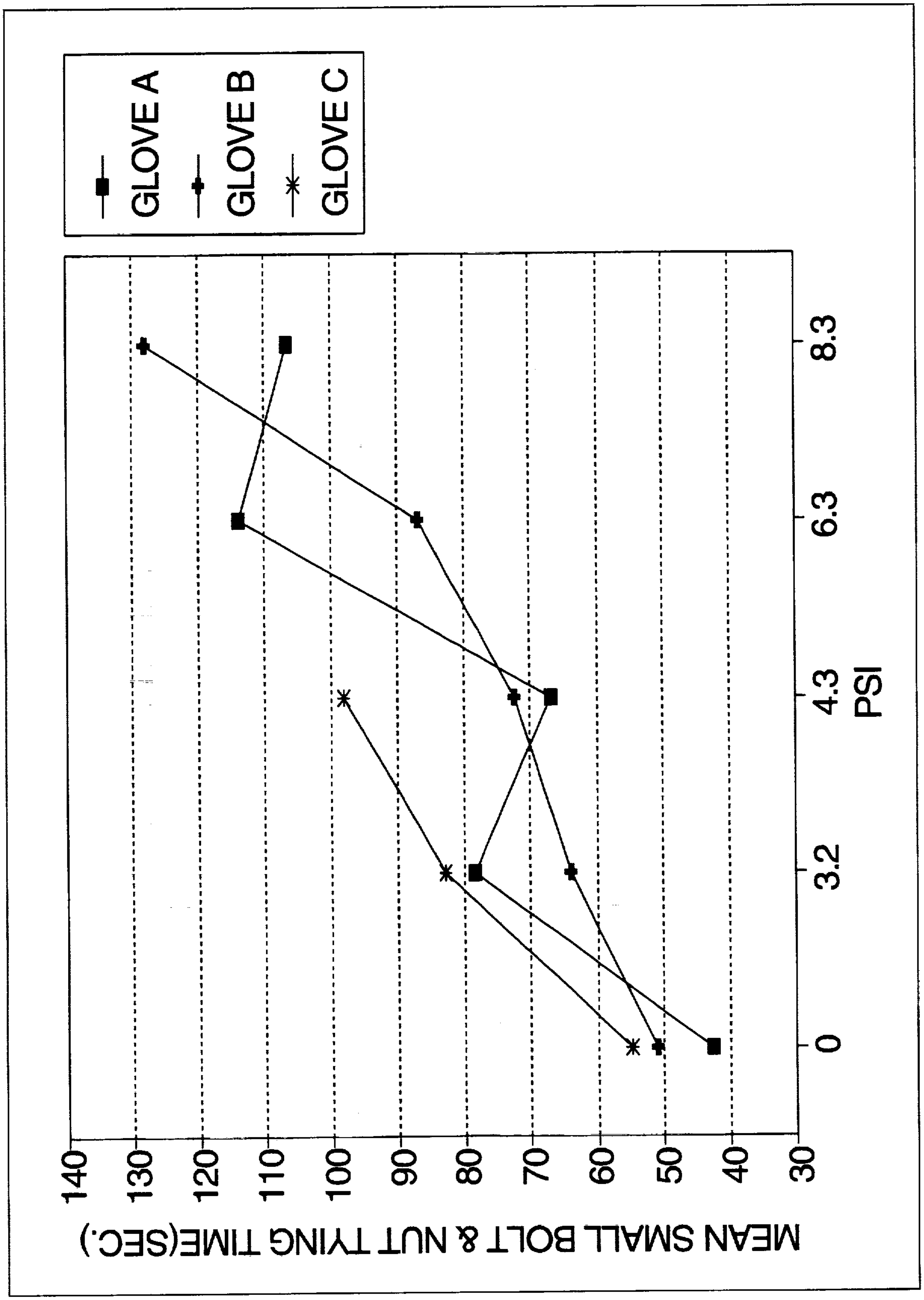

Figure 21. Glove*pressure interaction on small nut-and-bolt assembly time

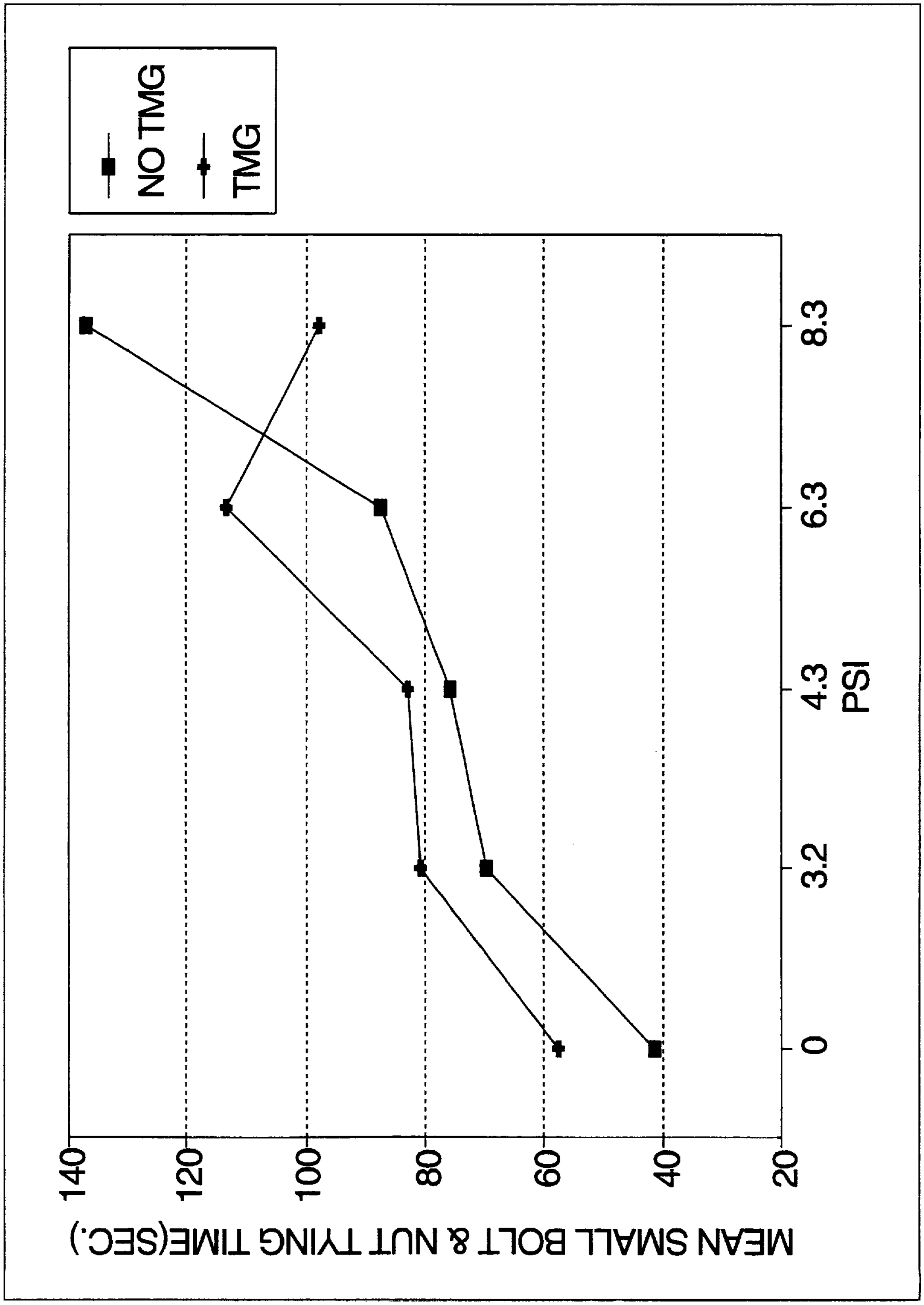

Figure 22. Pressure*TMG interaction on small nut-and-bolt assembly time

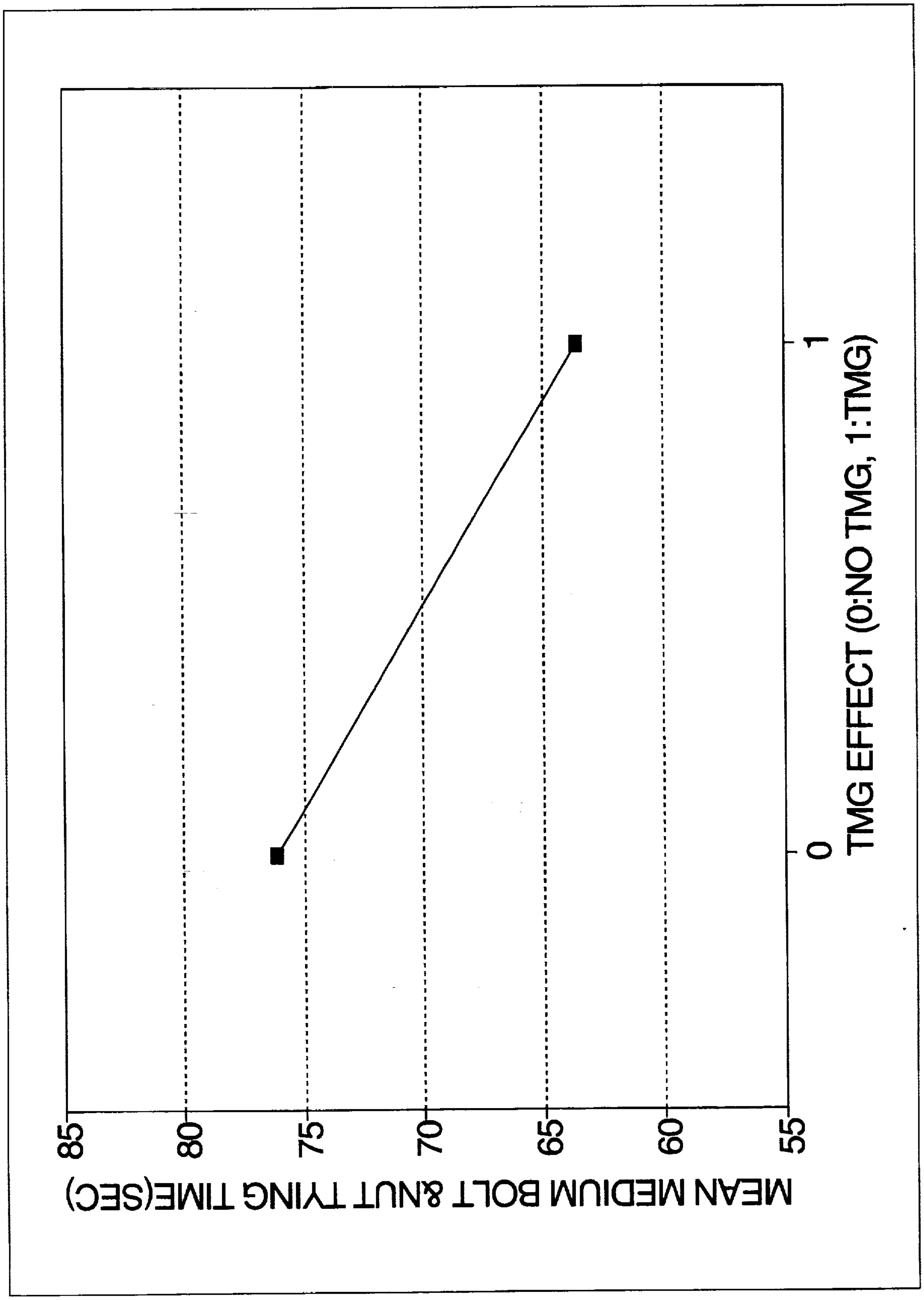

Figure 23. TMG effect on medium nut-and-bolt assembly time

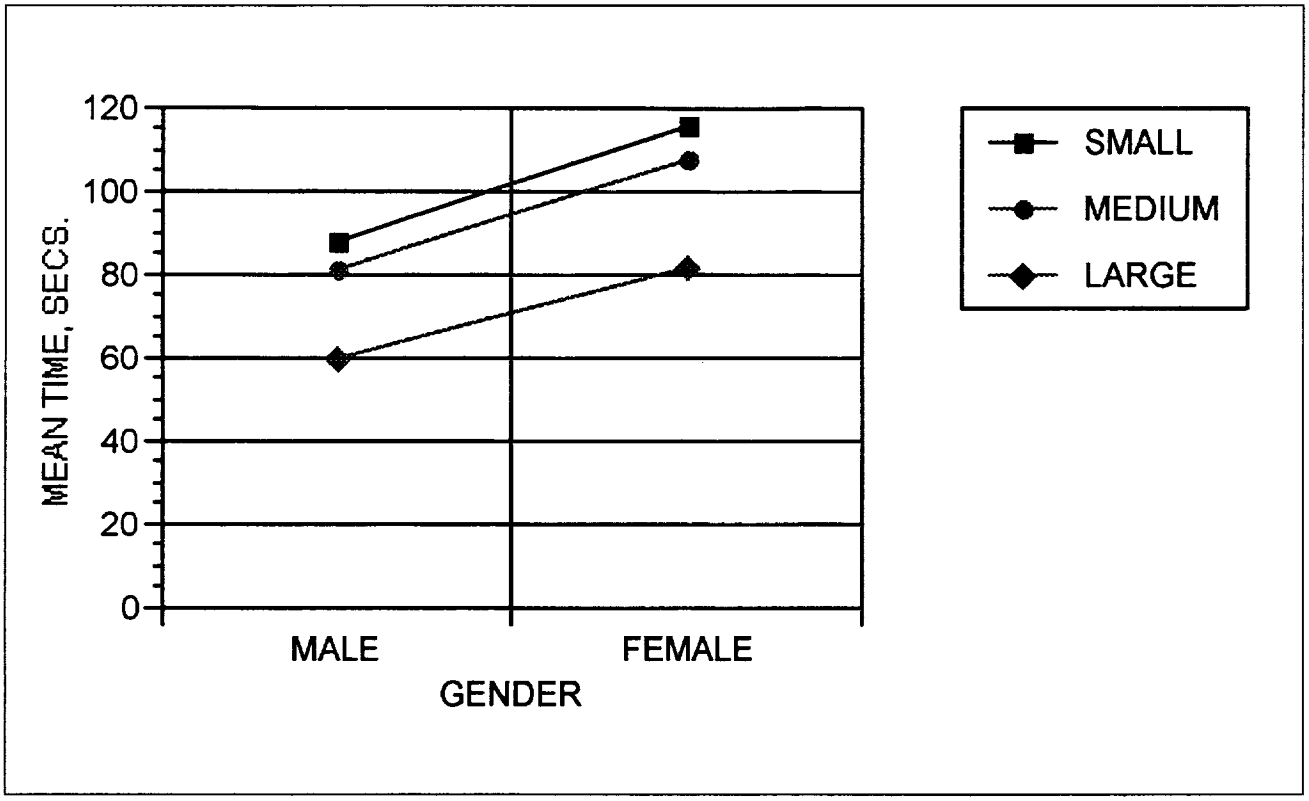

Figure 24. Gender effect on knot-tying time

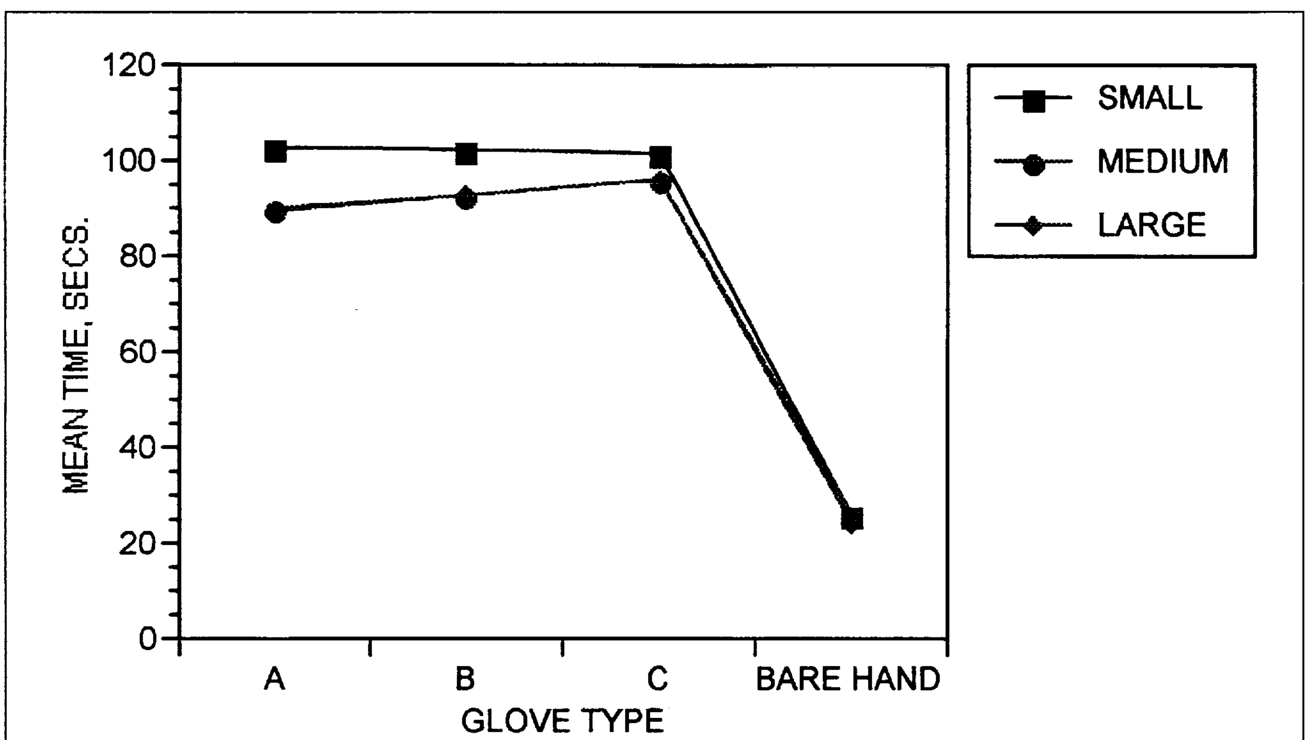

Figure 25. Glove effect on knot-tying time

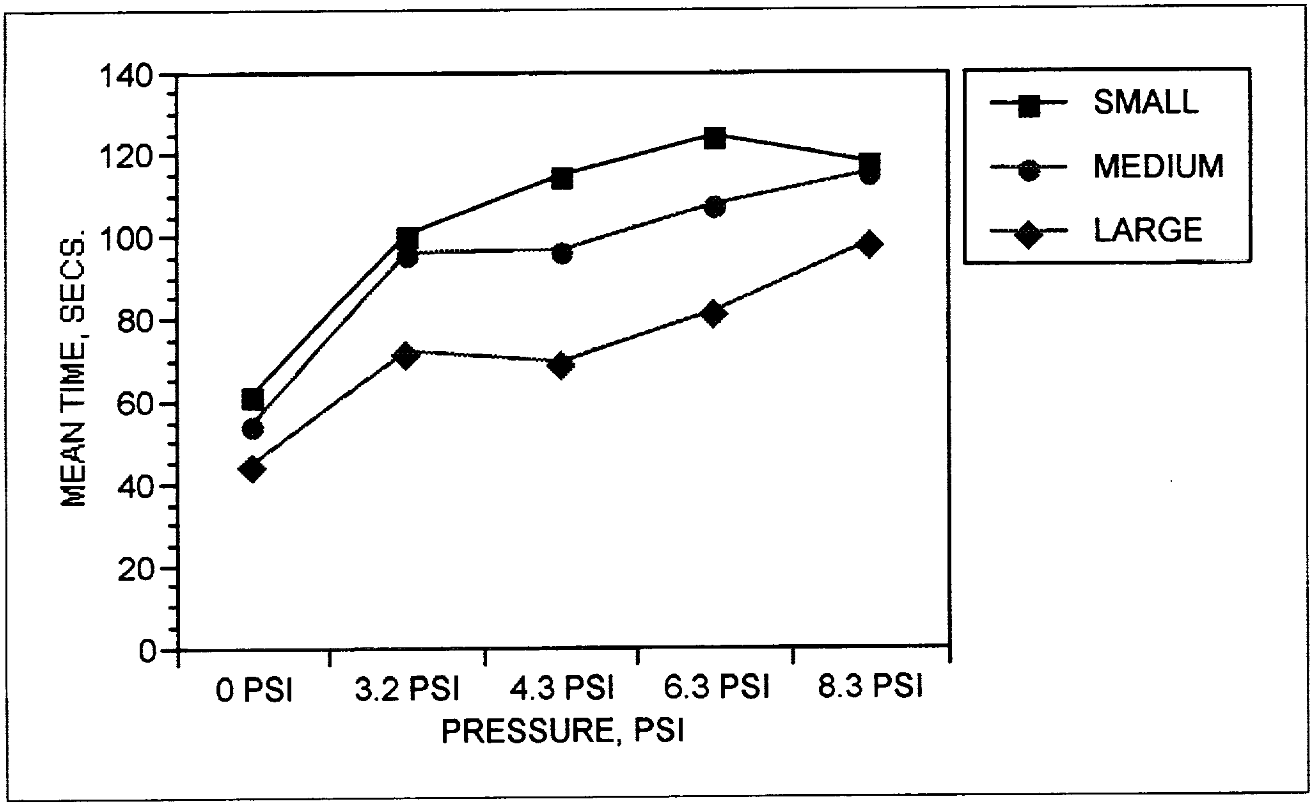

Figure 26. Pressure effect on knot-tying time

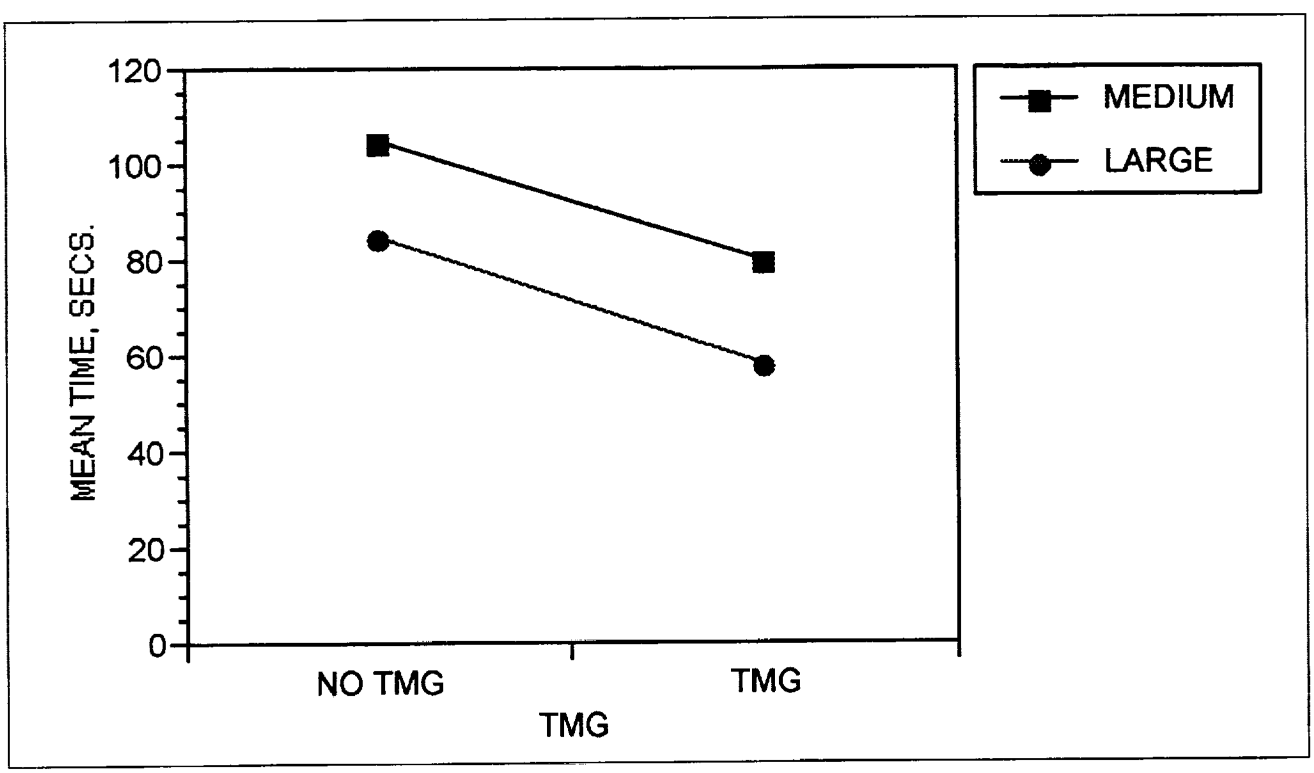

Figure 27. TMG effect on knot-tying time

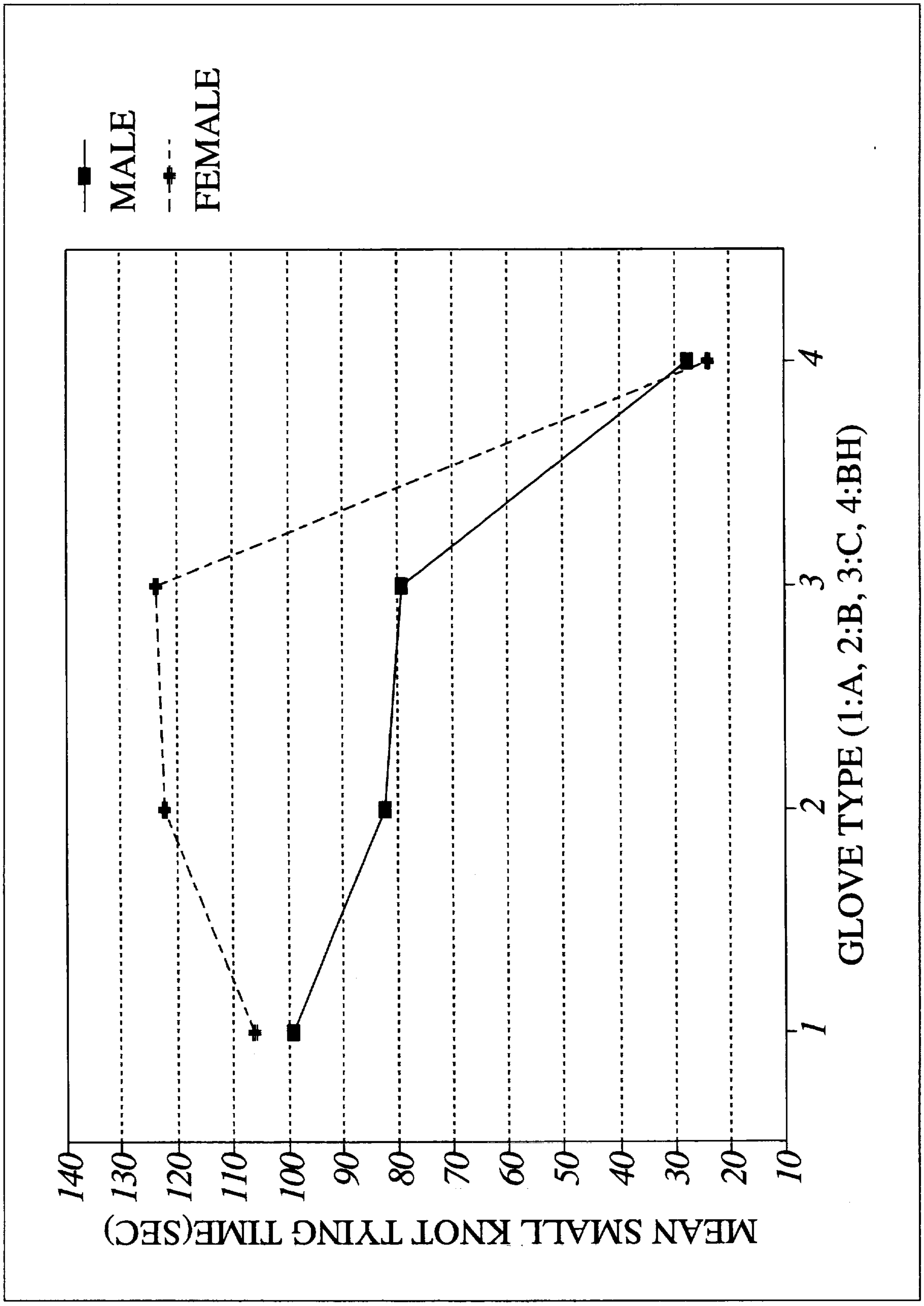

Figure 28. Glove*gender interaction on small knot-tying time

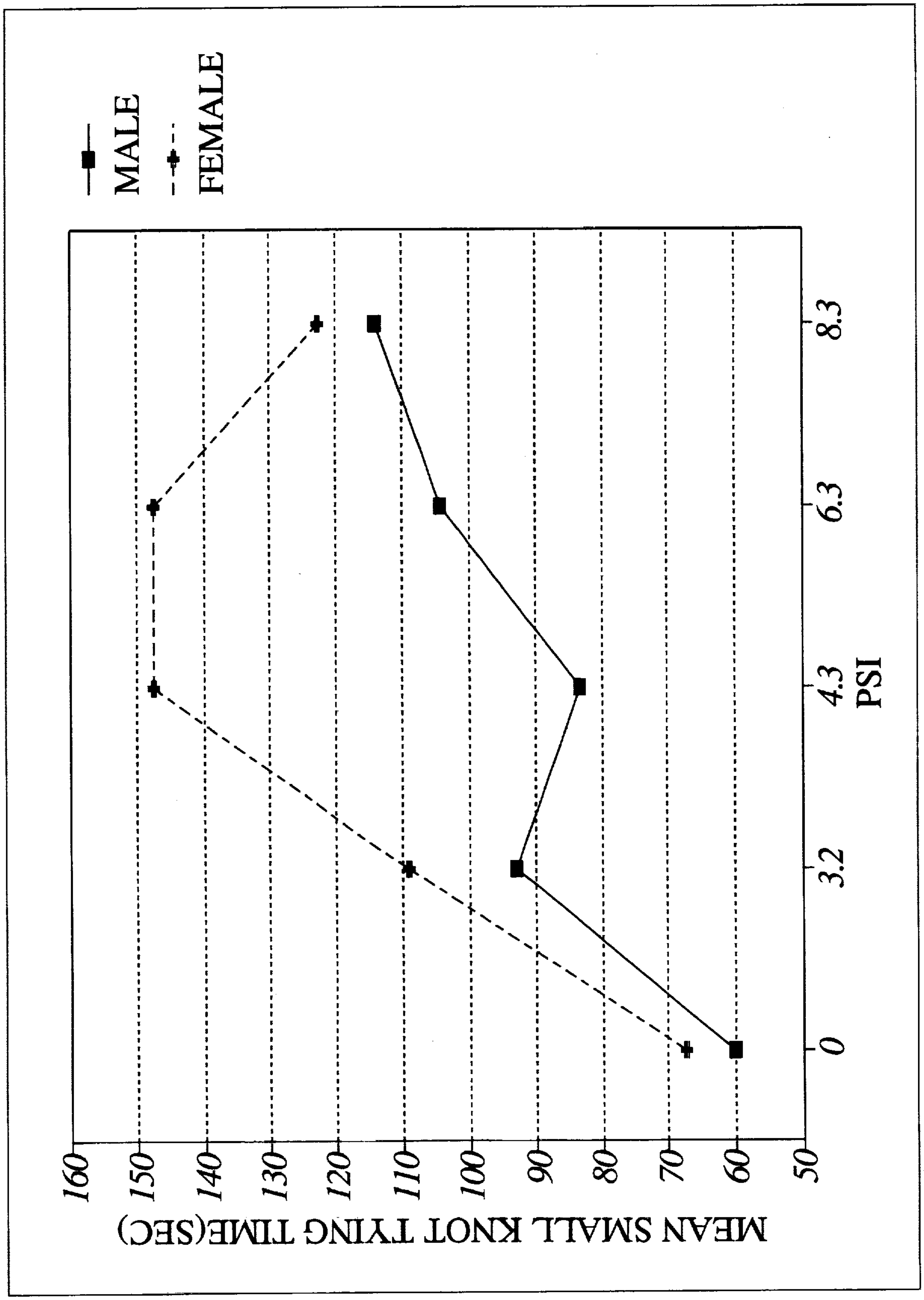

Figure 29. Gender*pressure interaction on small knot-tying time

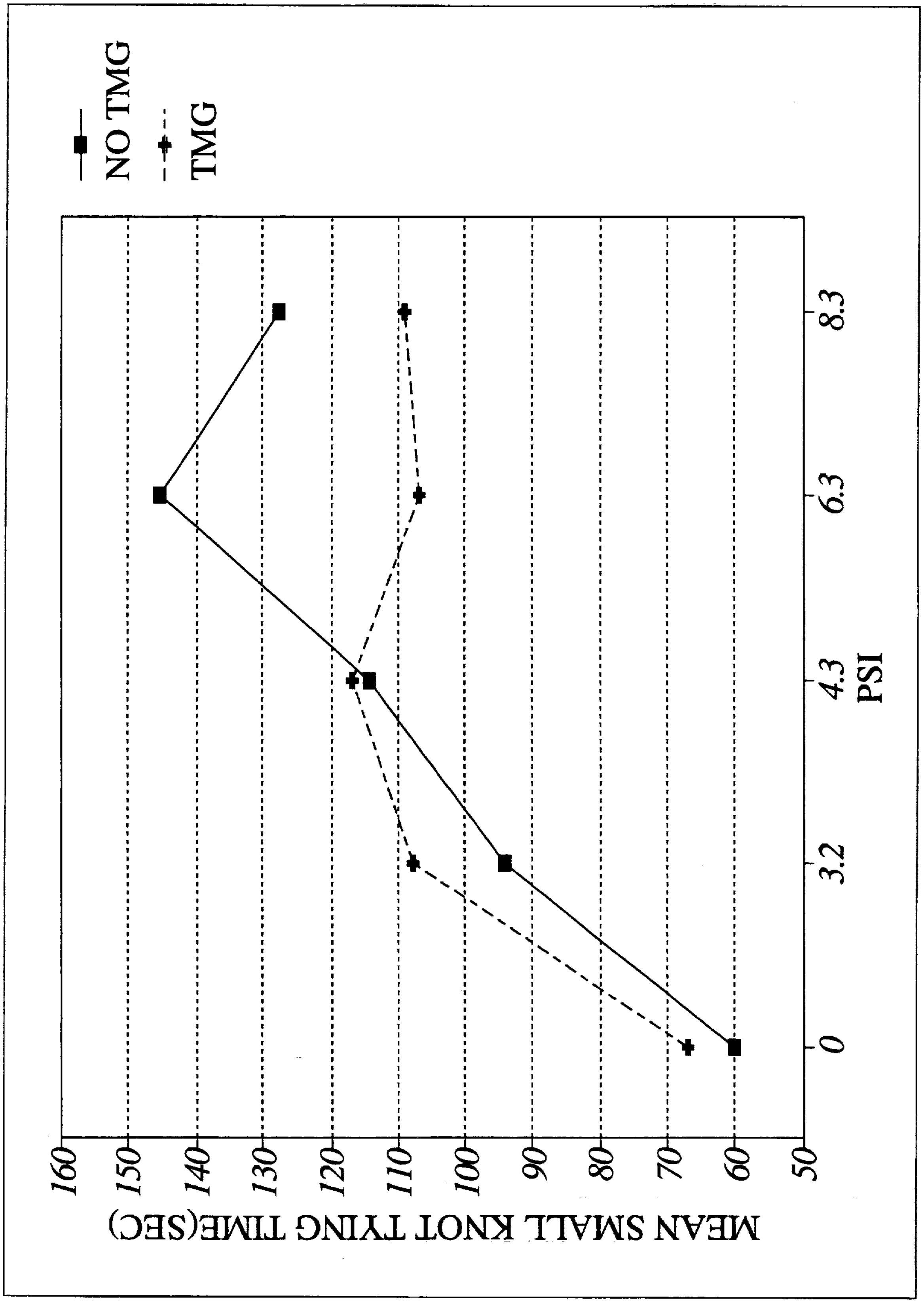

Figure 30. TMG*pressure interaction on small knot-tying time

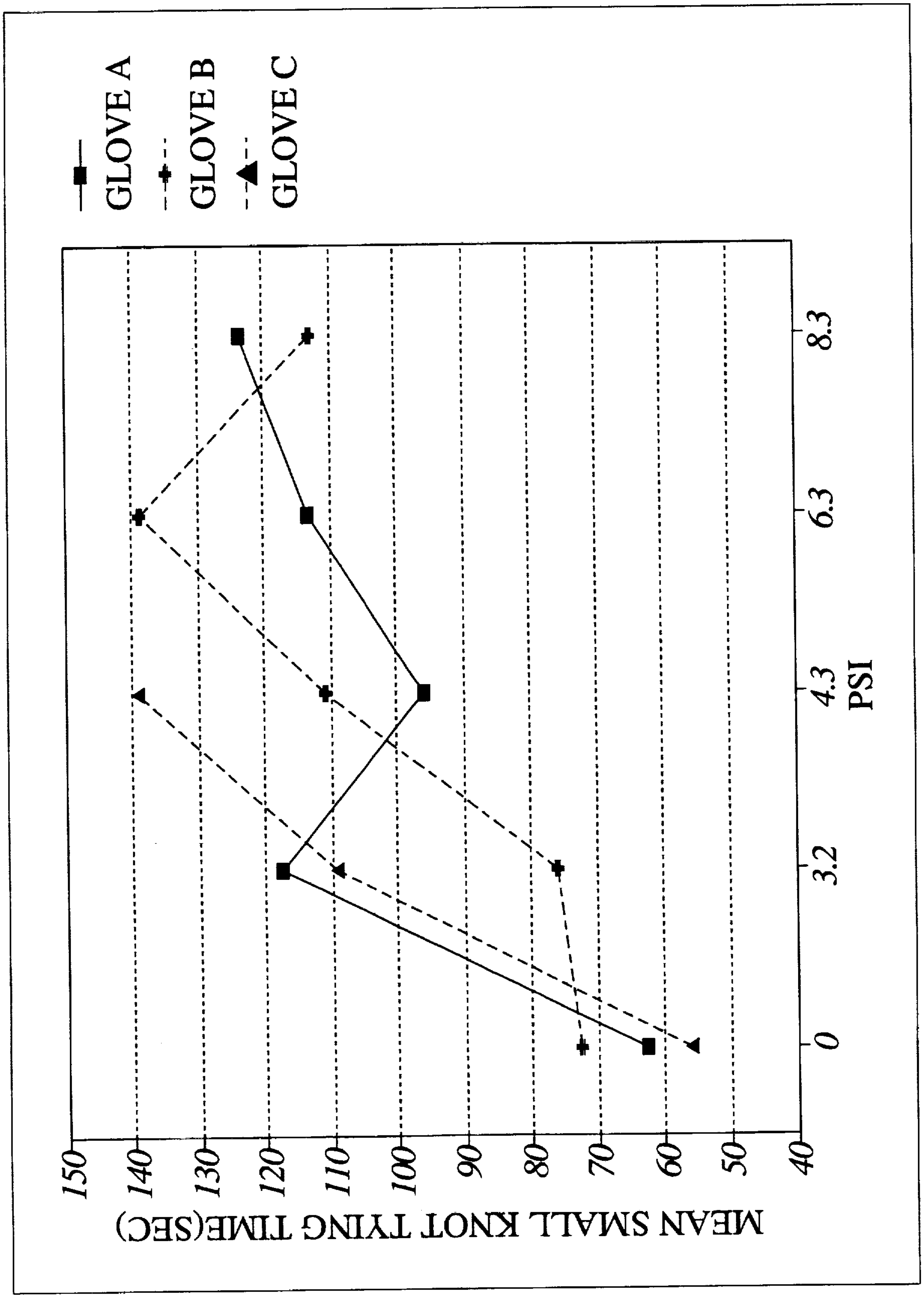

Figure 31. Glove*pressure interaction on small knot-tying time

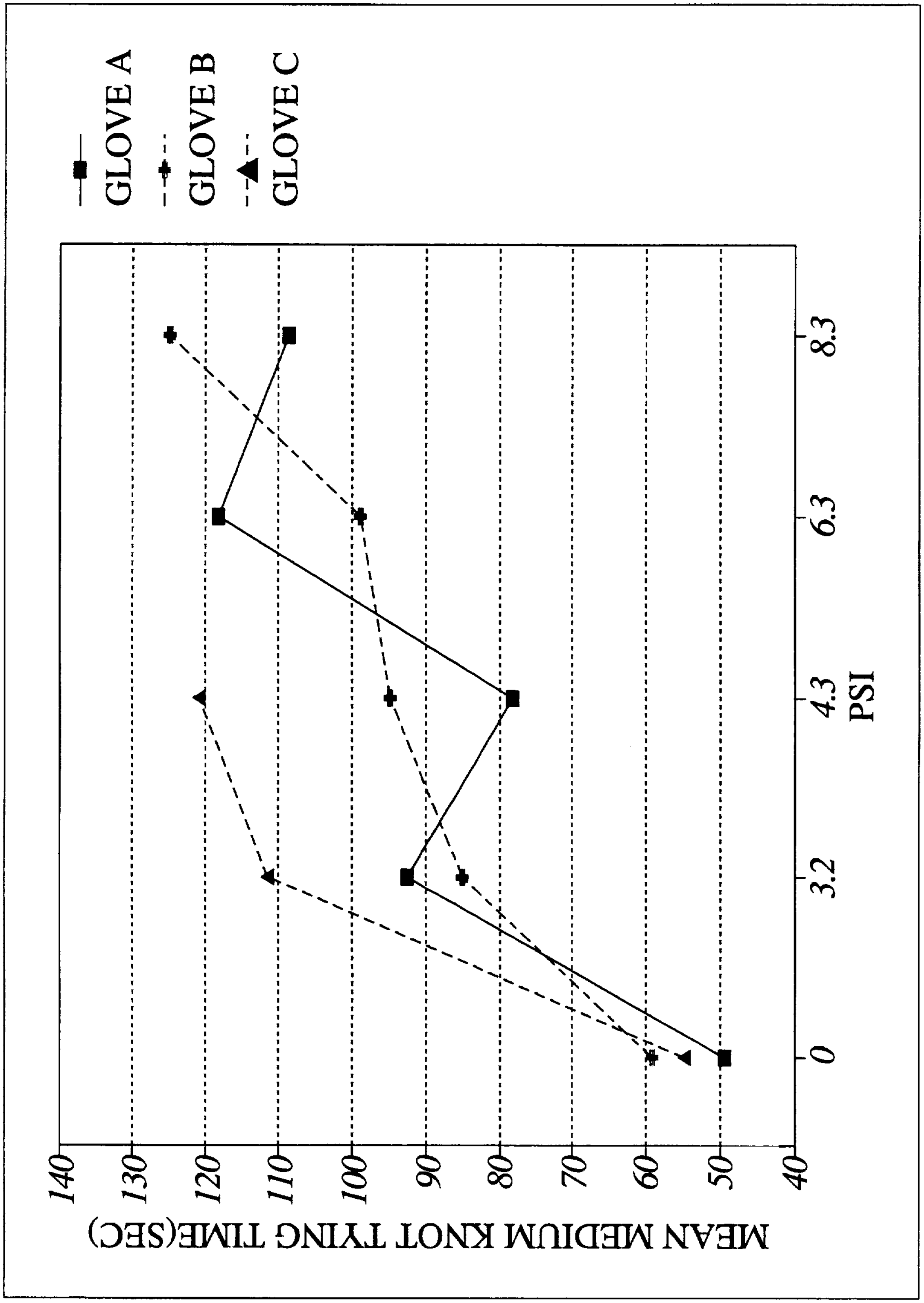

Figure 32. Glove*pressure interaction on medium knot-tying time

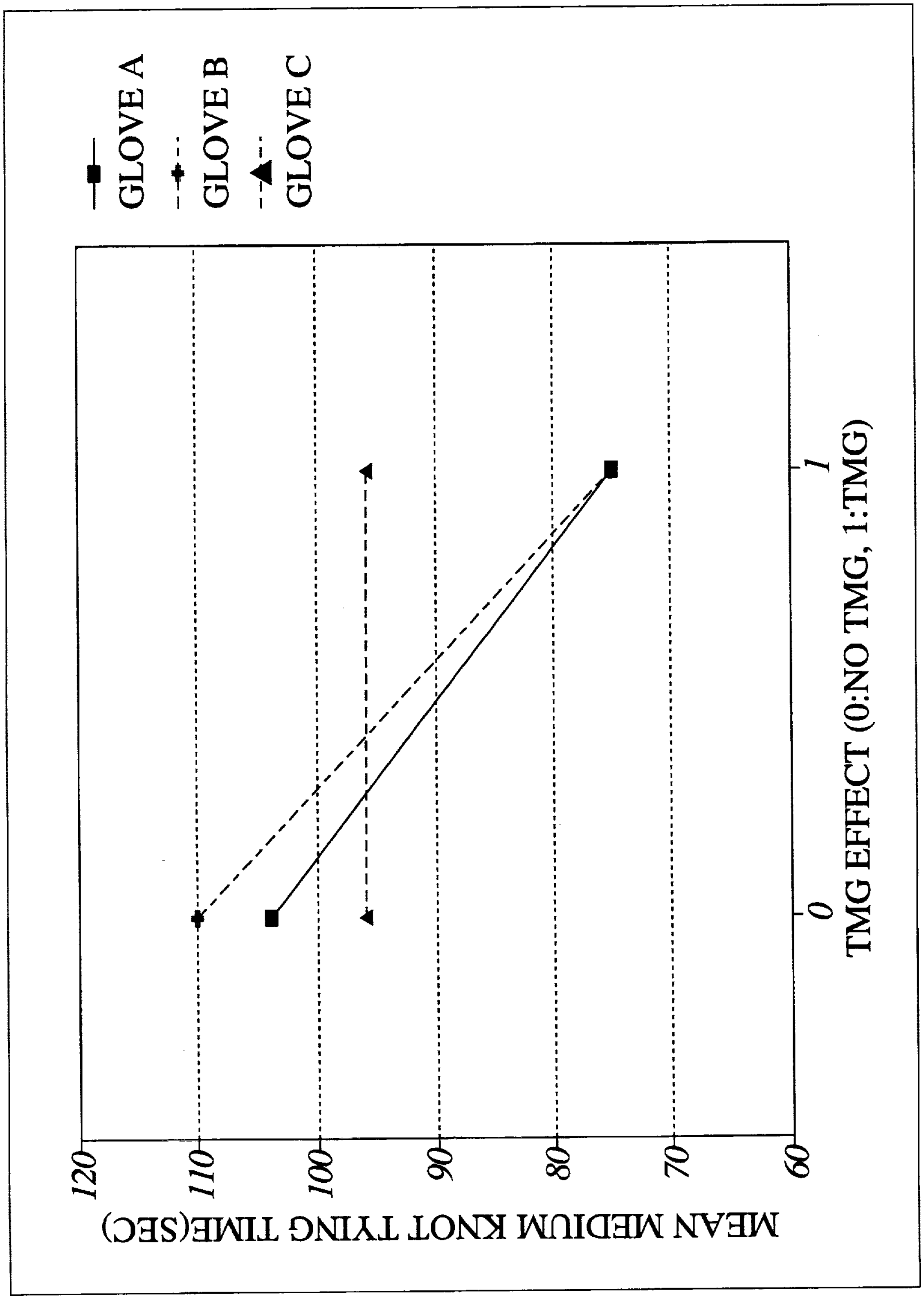

Figure 33. TMG*glove interaction on medium knot-tying time

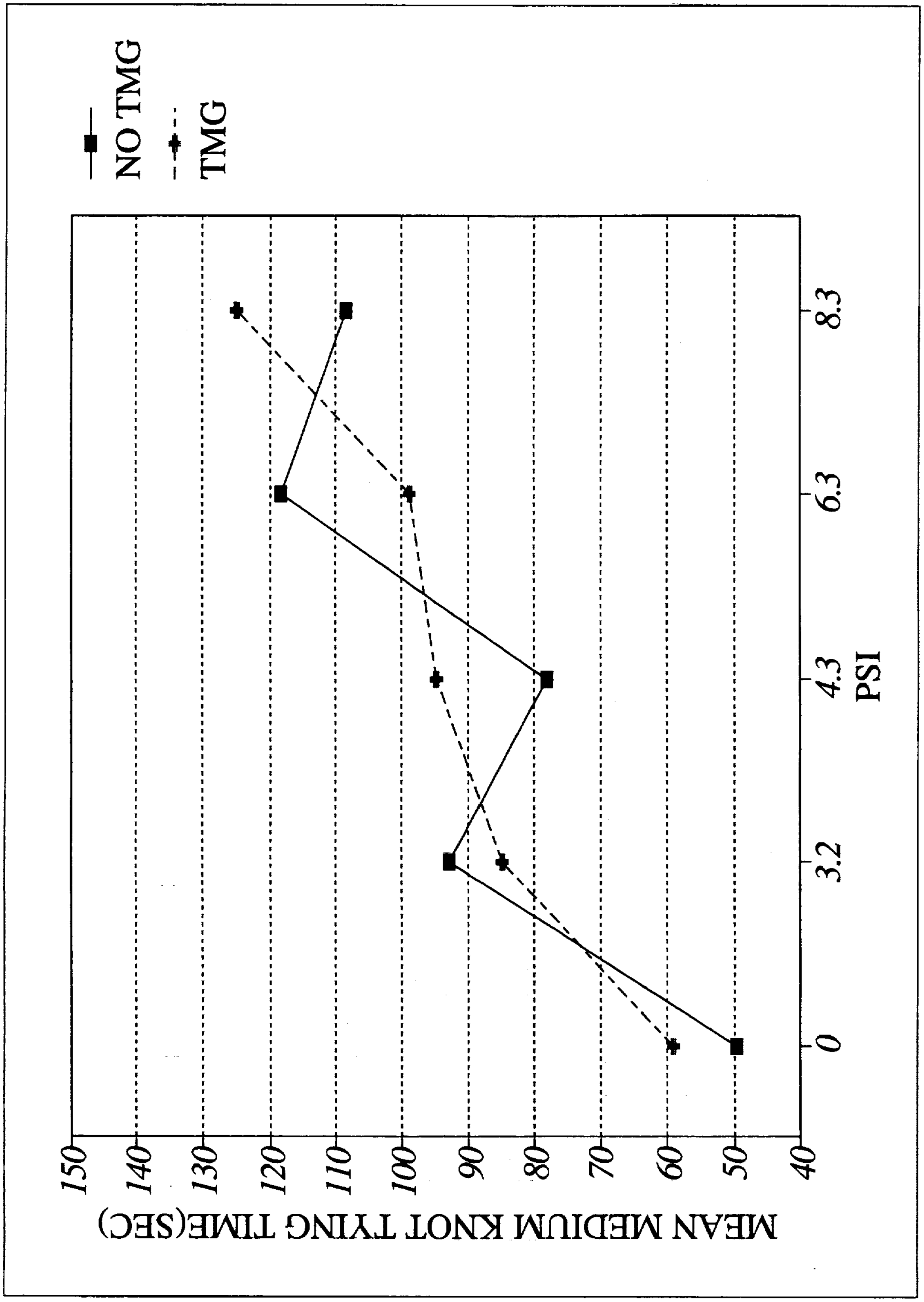

Figure 34. TMG*pressure interaction on medium knot-tying time

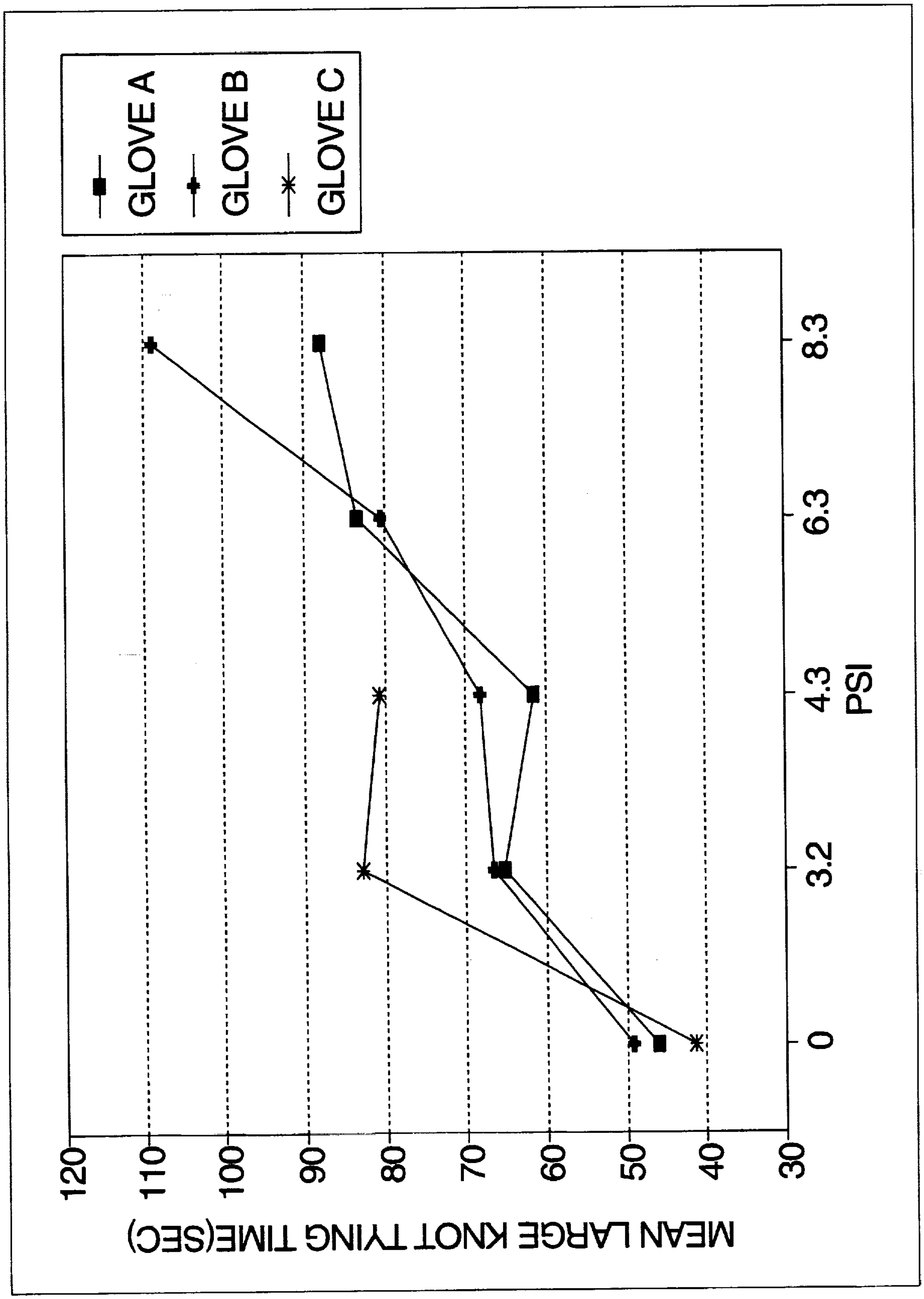

Figure 35. Glove*pressure interaction on large knot-tying time

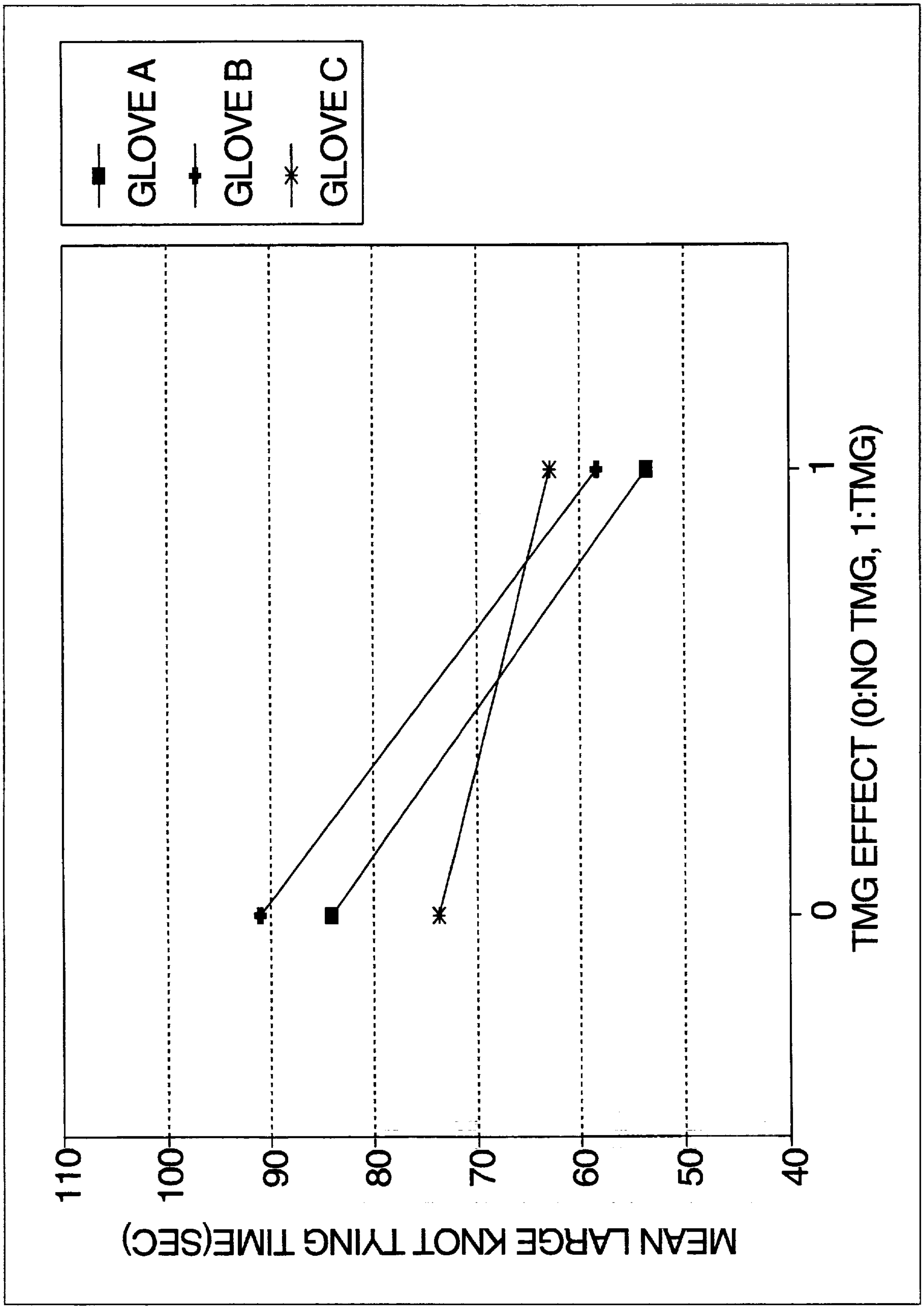

Figure 36. Glove*TMG interaction on large knot-tying time

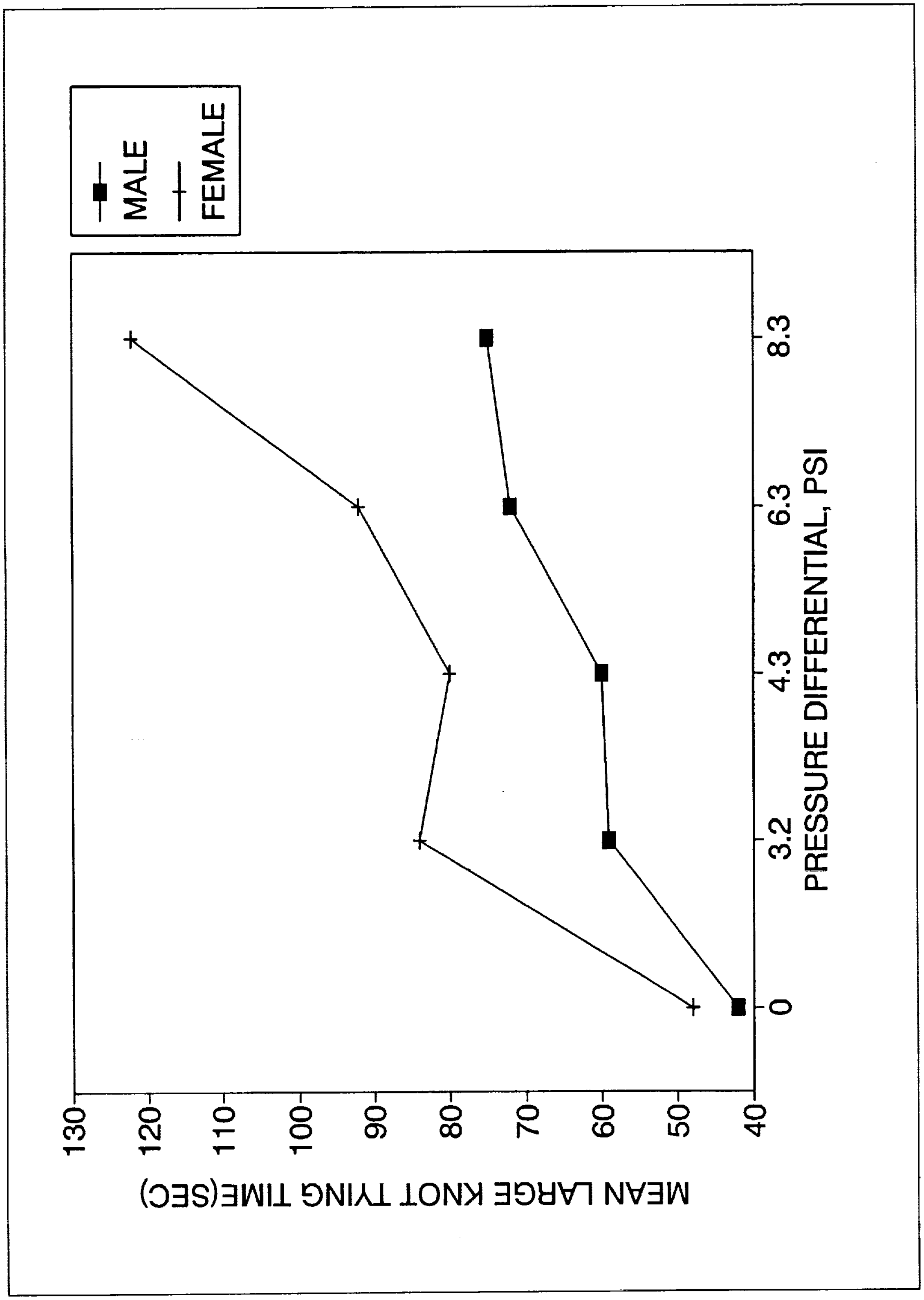

Figure 37. Gender*pressure interaction on large knot-tying time

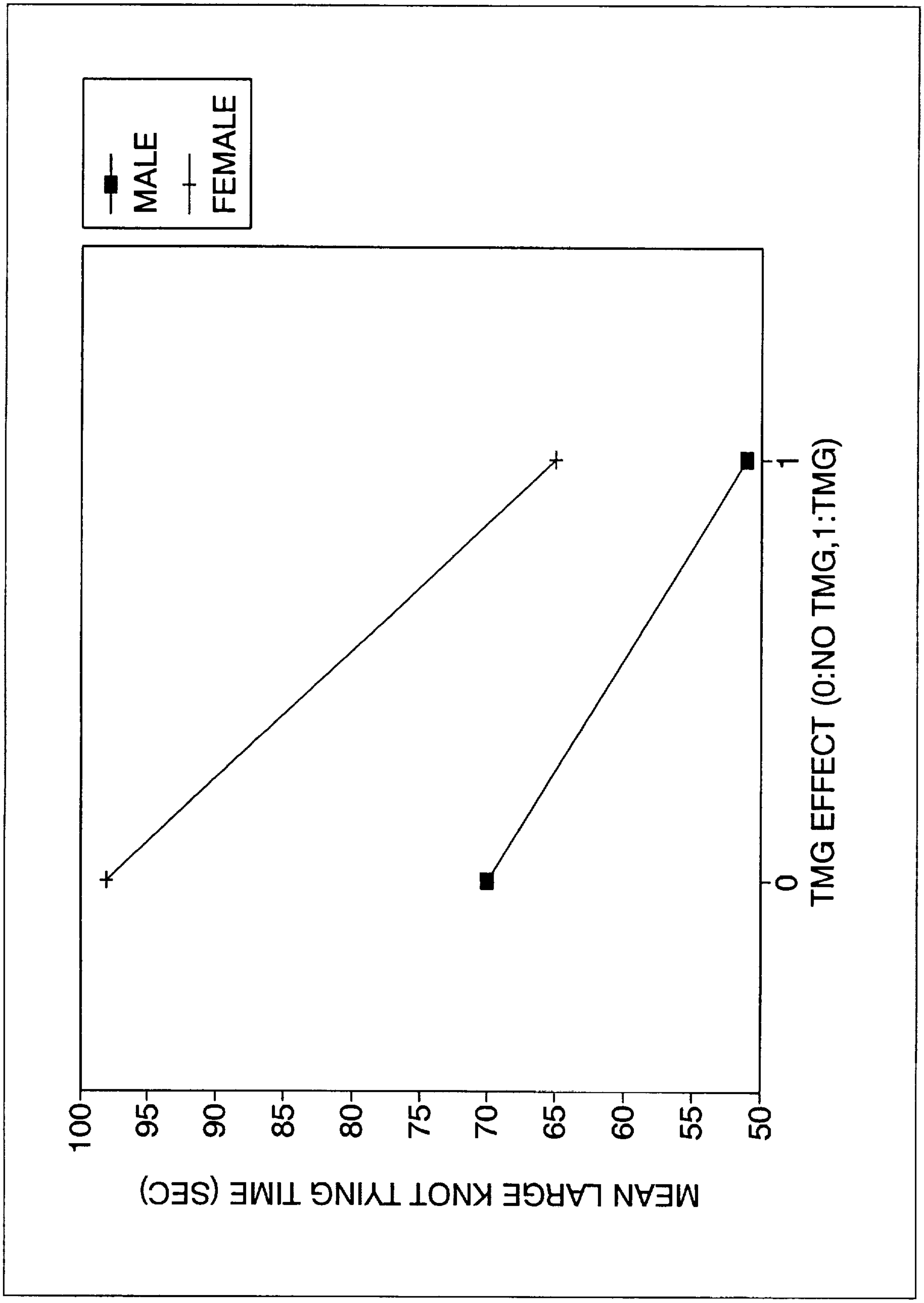

Figure 38. Gender*TMG interaction on large knot-tying time

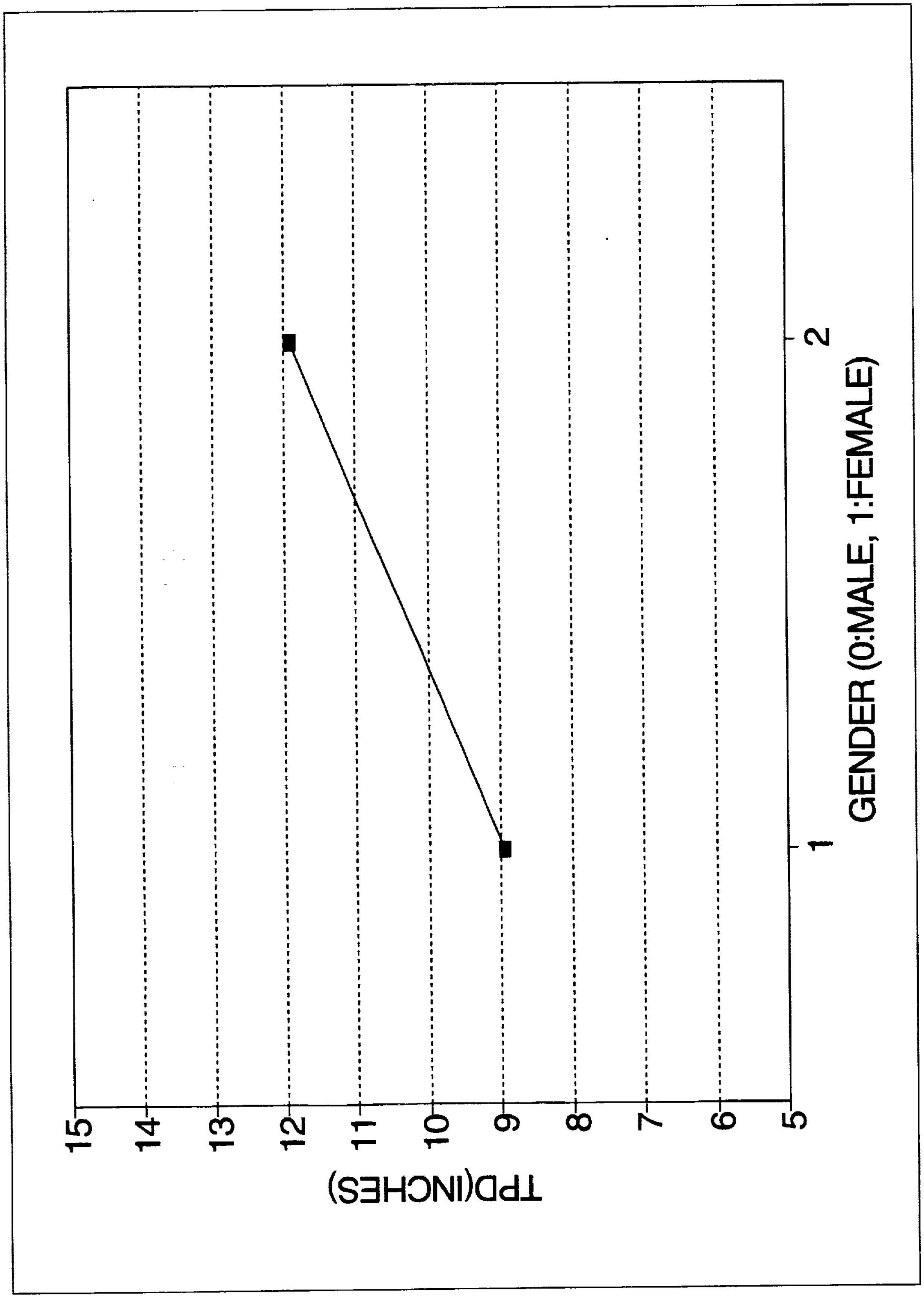

Figure 39. Gender effect on 2PD test

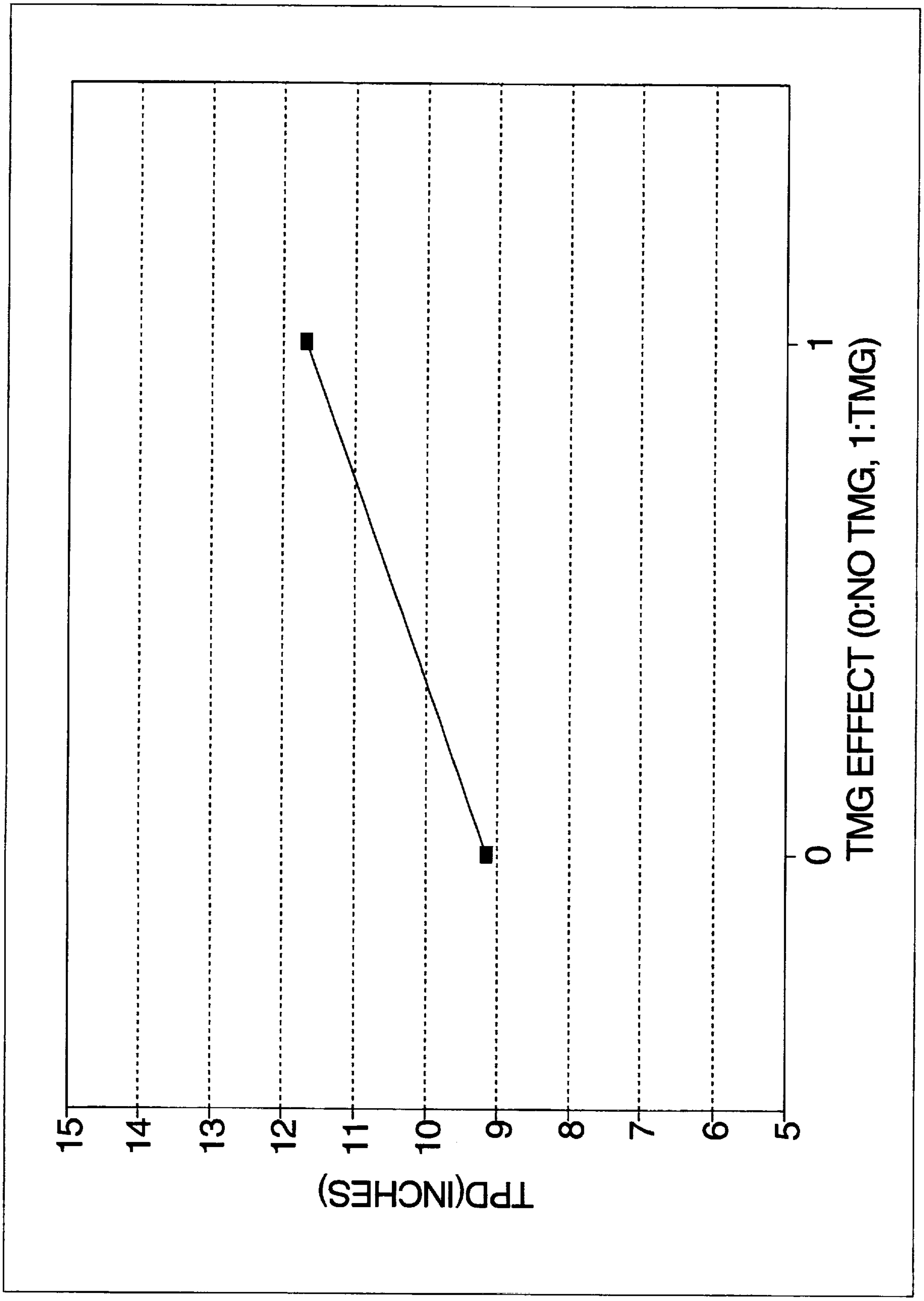

Figure 40. TMG effect on 2PD test

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13. ABSTRACT *(Maximum 200 words)*
The objective of this study was to assess the effects of EVA gloves at different pressures on human hand capabilities. A factorial experiment was performed in which three types of EVA gloves were tested at five pressure differentials. The independent variables tested in this experiment were gender, glove type, pressure differential, and glove make. Six subjects participated in an experiment where a number of dexterity measures, namely time to tie a rope, and the time to assemble a nut and bolt were recorded. Tactility was measured through a two point discrimination test. The results indicate that a) with EVA gloves strength is reduced by nearly 50%, b) there is a considerable reduction in dexterity, c) performance decrements increase with increasing pressure differential, and d) some interesting gender glove interactions were observed, some of which may have been due to the extent (or lack of) fit of the glove to the hand. The implications for the designer are discussed.

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