THE FORCES AND MOMENTS TRANSMITTED AT THE ARTICULATIONS OF THE UPPER EXTREMITY OF THE HUMAN DURING CERTAIN NORMAL ACTIVITIES

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ABSTRACT

Measurements have been made of the mechanics of the movement of the hand and arm during certain activities relating to normal function. The three dimensional spatial configuration has been measured and where relevant the external force exerted by the environment on the limb has been measured. From this information the components of force and components of moment to be transmitted at the wrist, elbow and shoulder axes have been calculated. Results are reported for activities relating to eating and dressing, as well as for situations where external force is involved for example by pulling a table or by assisted rising from the seated position. The information is presented as graphs to a base of time of the components of force and moment transmitted between the body segments in these activities. The load actions in the finger joints are presented as maxima measured during isometric tests related to grip and turning tasks.

INTRODUCTION

In rehabilitation the optimal target is the restoration of function to the level associated with the normal individual. A more realistic target is restoration of function to the level achievable by other persons in the same category of age and activity level. The design of aids for the disabled, therefore, should have in mind the possibility of the occurrence of optimal rehabilitation and the relevant hardware should have sufficient intrinsic strength and rigidity for this purpose. It is of interest therefore to have information relating to the actual levels of load which might be developed in certain situations for use in the design process and it may also be relevant to have these to be able to write a standard specification for mechanical acceptability tests. Information is therefore presented in this paper relating to the loading occurring in the hand and arm of normal individuals during certain tasks.

For the leg the functional specification is straightforward that statically it should support the trunk at the desired altitude and that dynamically it should allow translation in a controlled fashion. Most of the activities of the leg can be described under these two headings and the loading specification is therefore simplified.

The hand and arm undertake a wide range of movements in the activities of daily living and a selection was therefore made relating to those functions closely associated with the necessities of daily living and also associated with the difficulties that certain categories of disabled person may experience. For example in the hand the gripping strength of the fingers has to be sufficient to allow the transmission of the loads developed in the major muscles of the upper arm and shoulder to the object in question.

For the elbow and shoulder, however, it is necessary not only to consider those activities such as grooming, dressing, toileting, but also the activities that are required in the event of degeneration in the functional capability of the leg. It may be necessary to use crutches or drive a wheelchair or even if these aids are not necessary, frequently the arm is used to assist rising from a seated position or to readjust body position in bed or on other supporting surfaces.

Ideally information such as is herein presented should relate to individuals of various age groups and activity levels. In the first instance this investigation has been concerned with the loads developed by a series of clinically normal individuals in the general category of young adult and of active activity level.

TEST METHODS

For the activities involving large movements of the arm, tests were performed while the subject was holding in his hand a 1 kg mass simulating the clothes, eating vessel or other item which might normally be associated with the movement. Records were taken of the spatial configuration of the hand, forearm, upper arm and shoulder girdle by two 16 mm cine-cameras running at 50 Hz and viewing along orthogonal axes. The data was digitally smoothed as described by Nicol (1977) and double differentiated to obtain the component accelerations relative to the reference axes in the limb segments. The mass and mass properties of the appropriate arm segments were taken from the data of Contini and Drillis (1966) and the resultant inertial forces and moments were calculated. Where external force was affecting the loading on the elbow or shoulder a transducer was incorporated in the surface on which the hand was gripping and this transducer was invariably a six quantity device giving signals corresponding to the three components of resultant force and three component moments about its reference axes. In all cases it was found important to have this complete information since it was impossible to predict without measurement the actual direction and position of the resultant forces in any particular situation. Where loading on the individual fingers required to be measured, a transducer was incorporated into the area on which the finger of interest was pressing. A typical illustration of this is the tap shown in Fig. 1 where one of the radial gripping surfaces was cut from the tap and assembled to a load transducer which was then rigidly assembled to the base on which the tap itself was mounted. In this way the force transmitted by one finger was measured by the transducer while the whole hand was in the desired configuration gripping the tap.

For each junction between body segments, the resulting loading is reported as three components of force and three components of moment relative to a reference system centred at the centre of the joint in question and having one of its axes coincident with the centre line of a relevant long bone. The axes systems for the interphalangeal and metacarpal-phalangeal joints of the finger are shown in Fig. 2 and the reference axes for the wrist, elbow and upper humerus at the shoulder are shown in Fig. 3.

TESTS PERFORMED

Loading on the fingers was measured during isometric activities in the form of tap turning (using the transducer described) and pinching a block in the form of a cylinder of

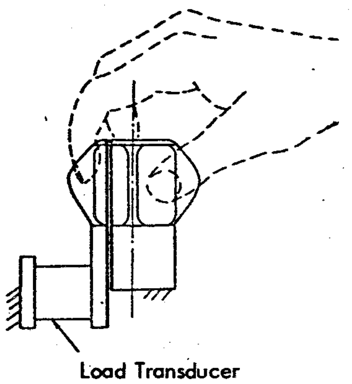

Fig. 1. The instrumental tap
from Berme et al 1977

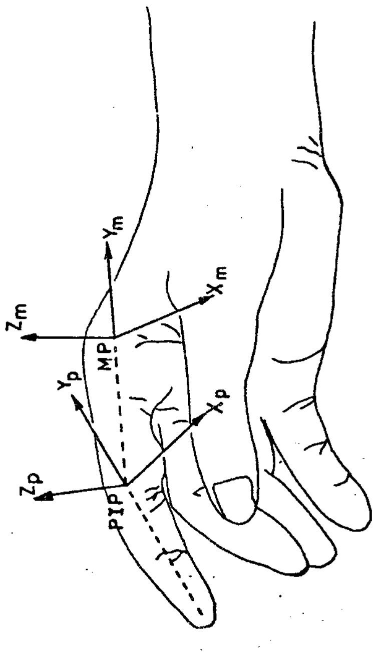

Fig. 2. Axis system for interphalangeal joint P and
metacarpophalangeal joint M.

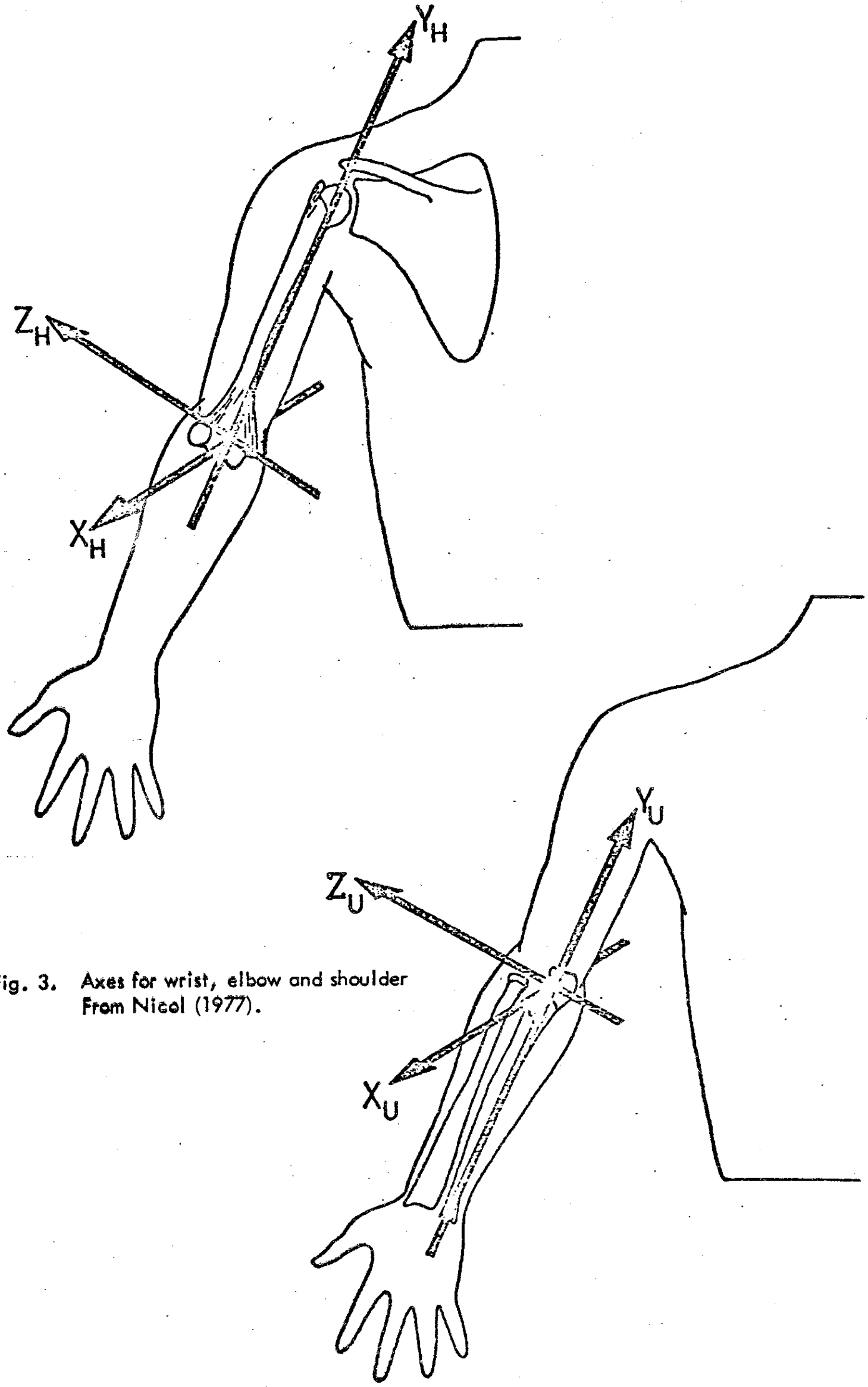

Fig. 3. Axes for wrist, elbow and shoulder From Nicol (1977).

45 m.m. diameter. Tests relating to wrist, elbow and shoulder loading were conducted during tests simulating reaching to a high shelf, eating, pulling a table closer to the test subject in a seated position, and during rising from a chair, with legs straight, under the assistance of the arms with the hands bearing against the arms of the chair.

RESULTS

Table 1 shows the resultant force and moment components transmitted at the proximal interphalangeal joint of the index finger during the two activities described for four test subjects, and Table 2 shows the corresponding information for the metacarpal-phalangeal joint in the same tests.

TABLE 1 Inter segment loading at PIP joint

Activity	Subject	Forces N			Moments mNm		
		FXp	FYp	FZp	MXp	MYp	MZp
Tap Turning	1	-	-1	-13	-462	-	-136
	2	-	-1	-13	-527	-	-105
	3	4	-5	-12	-463	-141	- 35
	4	2	-2	-13	-475	-	85
Pinching	1	-18	1	- 1	- 18	-	-667
	2	-21	2	4	155	-	-830
	3	-19	3	- 1	- 52	-	-706
	4	-19	4	- 1	- 39	-	-697

TABLE 2 Inter segment load actions at MP Joint

Activity	Subject	Forces N			Moments mNm		
		FXm	FYm	FZm	MXm	MYm	MZm
Twist	1	1	-1	-13	-890	-302	-301
	2	1	1	-13	-1025	-340	-242
	3	7	-3	-13	-1037	-380	18
	4	3	-	-13	-879	-336	-226
Squeeze	1	-15	-10	- 1	151	- 29	-1291
	2	-17	-11	4	442	- 97	-1595
	3	-15	-12	- 1	188	- 10	-1400
	4	-12	-15	- 1	- 90	- 34	-1251

The loading at the wrist, elbow and shoulder developed during the assisted rising from a chair activity, shown as Fig. 4, in which for reference a graph of height of rise to the common time base is shown.

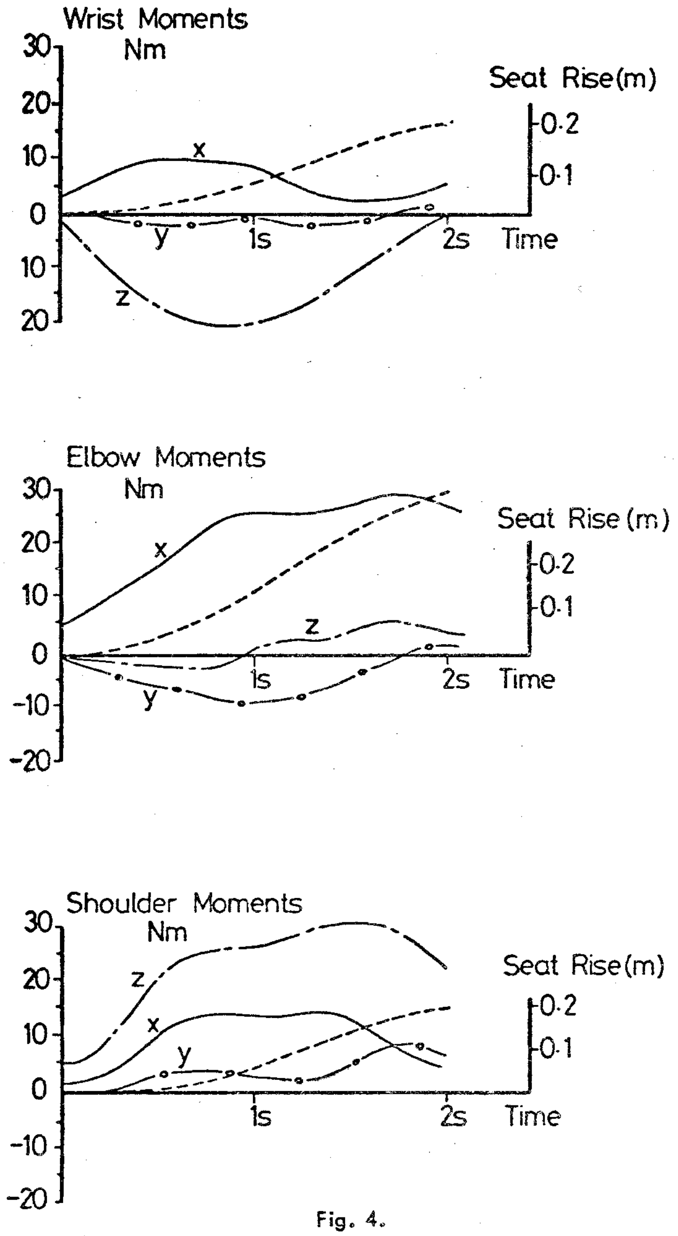

Fig. 4.

Loading corresponding to different activities is compared in Fig. 5 which shows the contribution to the M_z moment at the shoulder of the four different activities investigated. The consistency of performance between test subjects is illustrated in Fig. 6 which shows the shoulder M_z moment variation for three different test subjects in the assisted rising from chair activity.

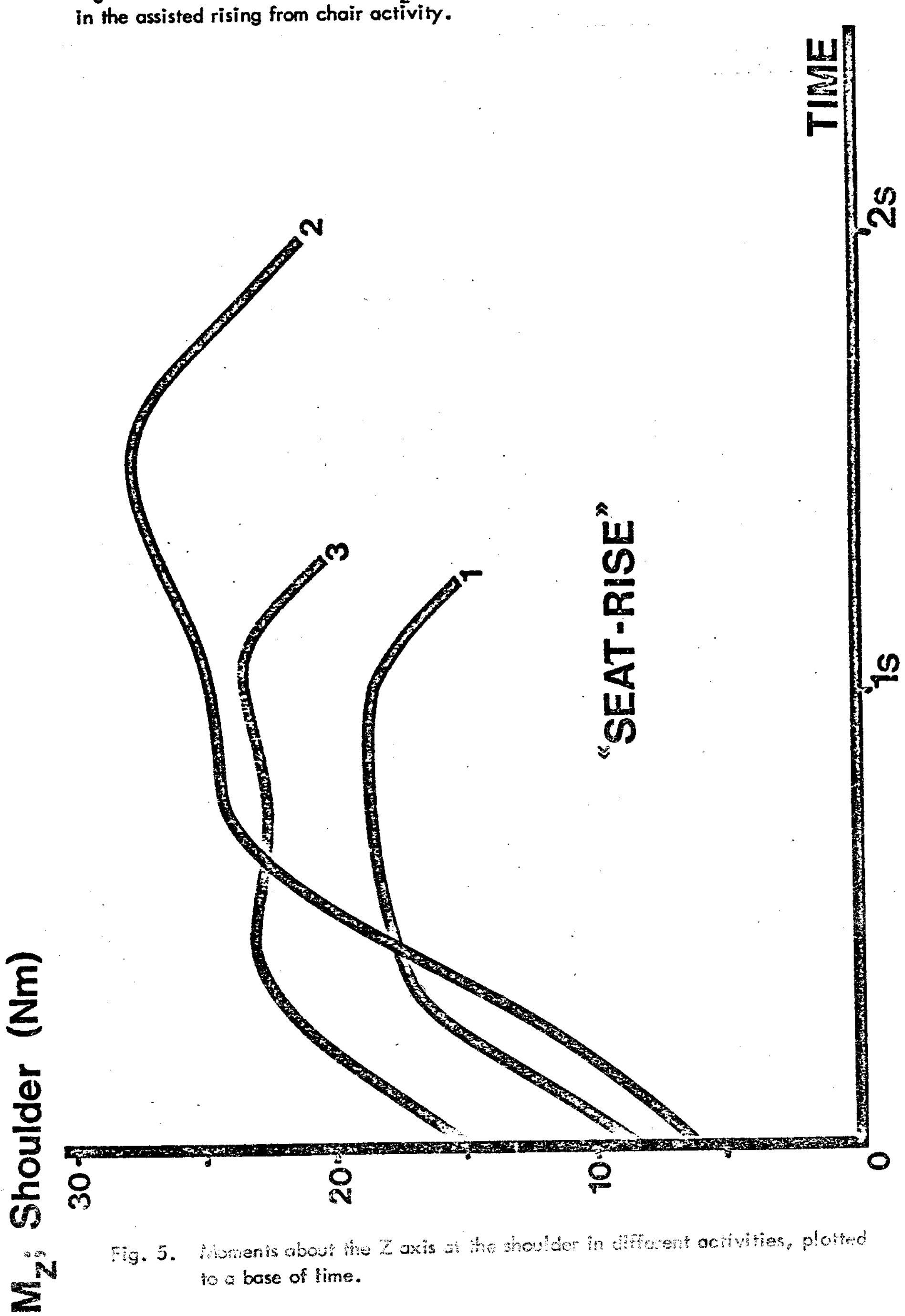

Fig. 5. Moments about the Z axis at the shoulder in different activities, plotted to a base of time.

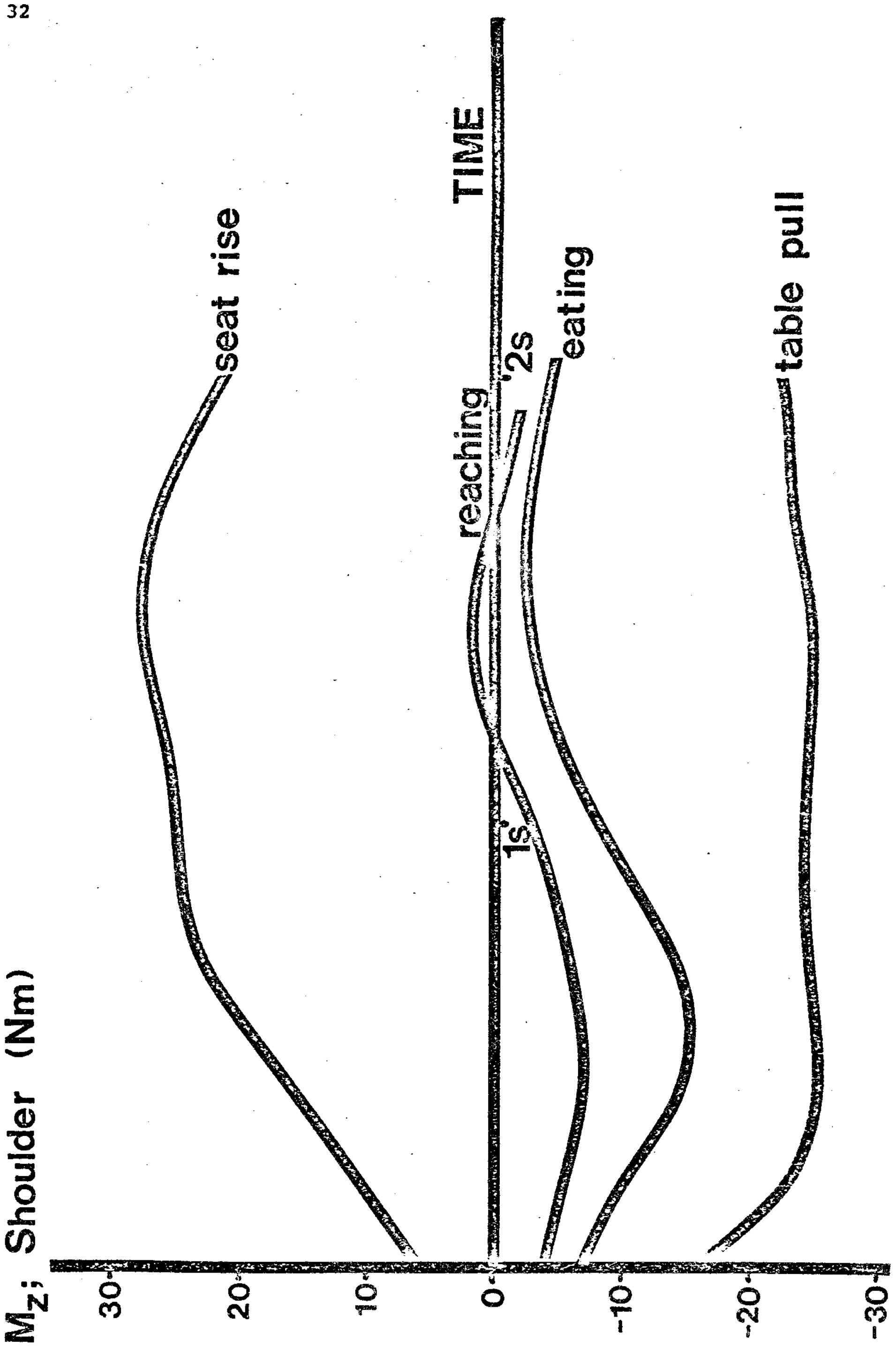

Fig. 6. Moments about the Z axis of the shoulder developed by three different test subjects, plotted to a base of time.

CONCLUSION

Preliminary data relating to inter-segment loading in the upper extremity is presented and moment values of up to 30 Nm. maximum were found. This compares to the maximum moment developed in the leg during walking at normal speed which may typically be 100 Nm.

ACKNOWLEDGMENT

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