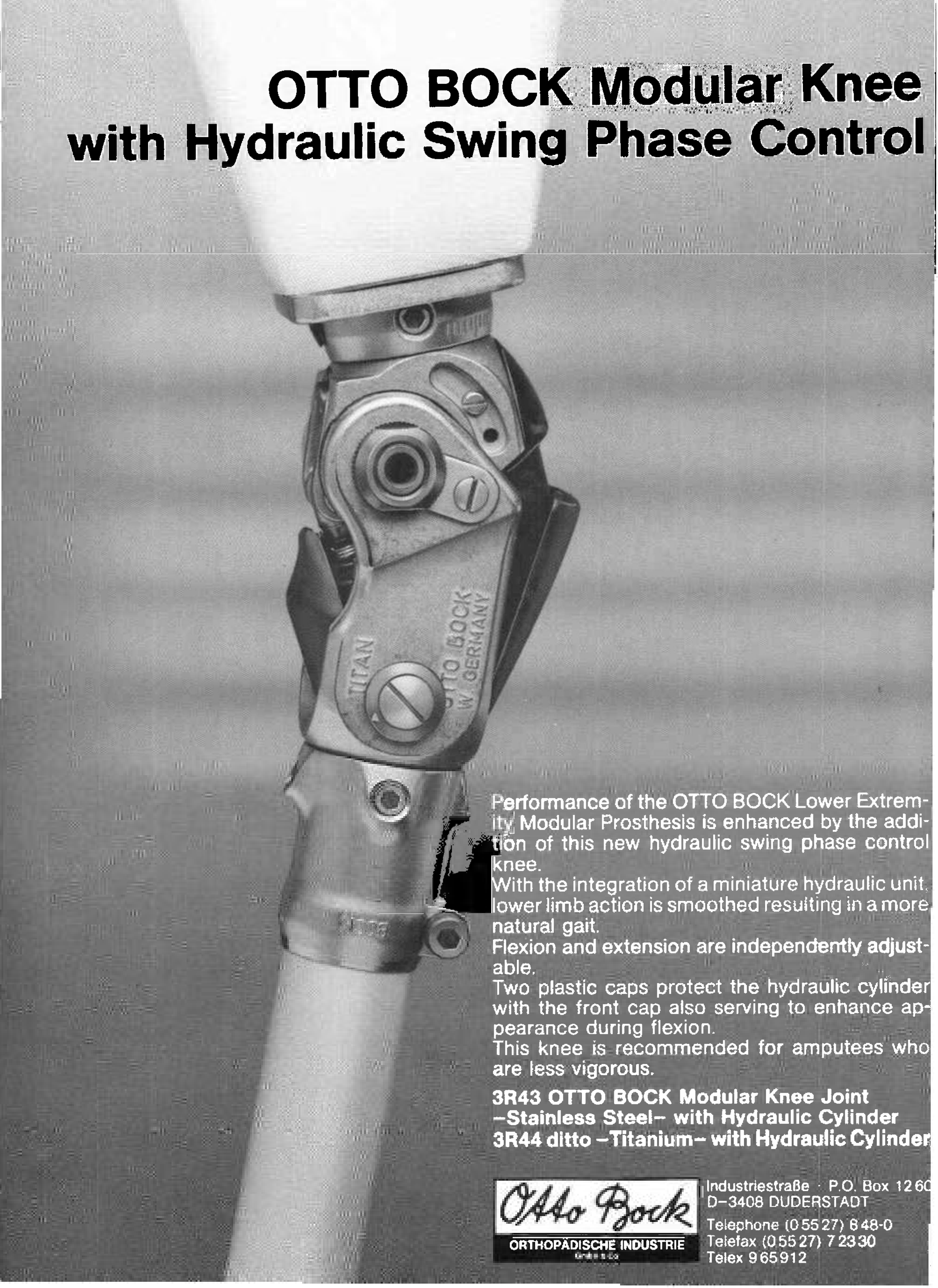
The Journal of the International Society for Prosthetics and Orthotics

Prosthetics and Orthotics International

Including Supplement on Wheelchairs

April 1991, Vol. 15, No. 1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Prosthetics and Orthotics International

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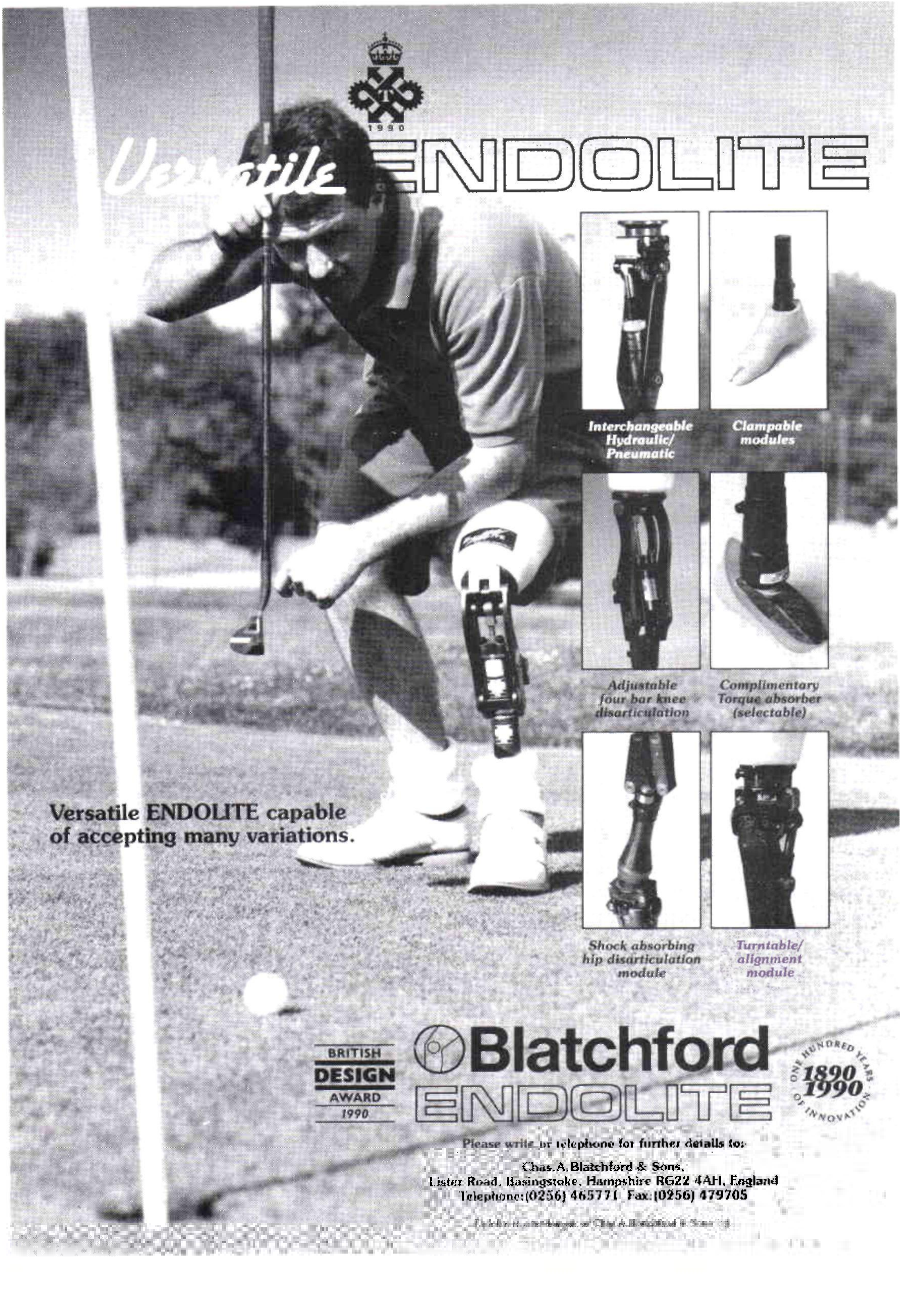
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The Journal of the International Society for Prosthetics and Orthotics

April 1991, Vol. 15, No. 1

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ISPO

Editorial

For the first time in four years the financial statement for the past fiscal year breaks even. It is a special pleasure to point out that the income from membership fees now matches the administration expenses, the costs of our professional register and the marginal cost of our Journal, Prosthetics and Orthotics International. These are activities directly related to the membership at large which could not be undertaken without the continuing support of the Society and Home for the Disabled (SAHVA) providing office facilities in Copenhagen, and the National Centre for Training and Education in Prosthetics and Orthotics in Glasgow supporting us with a great amount of non-reimbursed labour.

We are grateful to our Japanese colleagues for the succesful financial result of the Sixth World Congress, which was an essential event to expose ISPO to our multidisciplinary target groups and to increase our flock of members.

In 1990 we accrued expenses on printing of reports from workshops and in particular by arranging a Consensus Conference on Amputation Surgery. The Executive Board has considered these actions vital with respect to the continuous development of the treatment programmes for our consumers, the patients.

We wish to express gratitude to our financial supporters, SAHVA and the War Amputations of Canada.

Another highly essential field of our activities is participation in the international work devoted to the severely disabled and interrelated educational programmes. The expenses for this work are separately indentified in the accounts. The Executive Board intend also in the coming year to influence the international evolution of programmes as a major aim, although such activities set limits to the finances available for internal arrangements within the Society. A pertinent need is participation in the harmonization programme on education of prosthetists and orthotists in the European Community countries.

The Executive Board has set an unchanged membership fee for 1991 and hopes that it will not need to increase the fee during the triennium between World Congresses. In my position as Treasurer of the Society I will express my admiration and gratitude towards the laborious participation in the international work by our representatives, who are not relieved from their daily tasks and only accrue reasonable expenses in accordance with practice and rules for Danish Civil Servants. The Society could not survive on the international platform without such dedicated contributions.

The only way of improving our economy is by arranging profitable courses and congresses, but unfortunately the international political situation has led to cancellation of the first update course on amputation surgery, which was supposed to be a natural spin-off from the Consensus Conference and was planned for Spring 1991. The Executive Board will continue to work on setting up such events, but sensitive factors beyond our control mean that for the meantime the next major event planned for is the Seventh World Congress in Chicago in 1992. However, we hope for all the support required for any intermediary programme we are able to launch before then.

J. Steen Jensen
Treasurer

Prosthetics and Orthotics International, 1991, 15, 2–5

ISPO Statement of Accounts, 1990

Auditors' Report

We have audited the financial statements for the year ended December 31, 1990.

The audit has been performed in accordance with approved auditing standards and has included such procedures as we considered necessary.

The financial statements have been prepared in accordance with statutory requirements and the constitution of the society and generally accepted accounting principles. In our opinion the financial statements give a true and fair view of the state of the association's affairs on December 31, 1990 and of the result for the year then ended.

Copenhagen, March 13, 1991
Schøbel & Marholt
Søren Wonsild Glud
State Authorized Public Accountant

Accounting Policies
Securities
Bonds and shares are valued at the lower cost on market.

Office equipment
Computer and office furniture have been valued at cost less depreciation, computed straight line over 5 years.

Income Statement for the Year 1990

		1990	1989
SUMMARY			
Society membership fees (note 1)		1.017.829	899.545
Sponsorship (note 2)		132.430	135.444
Meeting with other organisations (note 3)		(147.719)	(135.565)
Conferences, courses etc. (note 4)		(204.220)	—
World Congress 1989, Kobe Japan (note 5)		82.370	(117.523)
Prosthetics and Orthotics Int. (note 6)		(84.584)	(65.242)
Professional register		(32.934)	(8.681)
Publications (note 7)		3.695	(106.018)
		766.867	601.960
Administration expenses (note 9)		(858.387)	(998.111)
Primary result		(91.520)	(396.151)
Interest (note 8)		318.345	217.308
Dividend (note 8)		1.755	74.628
Maturity yield (note 8)		4.495	2.792
Change in market value of securities (note 8)		(66.224)	(85.303)
Result for the year	DKK	166.851	(186.726)

Balance sheet as of December 31, 1990

		1990	1989
ASSETS			
Cash		567.577	1.519.649
Accounts due			
Accrued interest		70.155	48.855
Advertising receivable		81.182	27.725
Prepayment, World Congress, Chicago		130.080	–
Advance funding of World Congress 1980		87.437	87.437
Receivables		368.854	164.017
Securities (note 11)		2.869.239	1.999.849
Office equipment (note 10)		24.313	48.625
Total Assets	DKK	3.829.983	3.732.140

		1990	1989
LIABILITIES AND CAPITAL			
Liabilities			
Short-term liabilities			
Accrued expenses		50.023	85.110
Accrued printing expenses		120.000	111.679
Prepaid membership fees		6.591	40.000
Prepaid advertising income		2.115	5.285
Prepaid subscription income		88.000	93.663
		266.729	335.737
Provisions			
Provision World Congress 1980		87.437	87.437
Capital			
Capital January 1, 1990		3.308.966	3.495.692
Result for the year		166.851	(186.726)
Capital December 31, 1990		3.475.817	3.308.966
Liabilities and Capital	DKK	3.829.983	3.732.140

Contingent liabilities (note 12)

Notes to the Financial Statements

1. SOCIETY MEMBERSHIP FEES
Membership fees consist of payments from 2306 listed members, including 45 honorary members.

		1990	1989
2. SPONSORSHIP			
Contribution from the War Amputations of Canada		32.430	35.444
Contribution from SAHVA		100.000	100.000
	DKK	132.430	135.444

3. MEETINGS IN OTHER ORGANISATIONS

Other meetings 1989	–	(66.292)
American Academy Prosth. Orth.	(14.664)	(14.646)
World Orthopaedic Concern	(4.640)	(3.916)
WHO – Geneva	(16.503)	(5.843)
Education Commission, Interbor	(20.513)	(24.869)
AOPA	(61.397)	–
RI Dublin	(20.093)	–
ACOPPRA – Costa Rica	(4.934)	–
ISO TC 173	(4.975)	–
DKK	(147.719)	(115.565)

4. CONFERENCES, COURSES, etc.

Consensus Conference Oct. 1990	(204.220)	–
DKK	(204.220)	–

5. WORLD CONGRESS 1989, KOBE JAPAN

Net result of the World Congress	154.321	–
Accountant	(12.000)	–
Secretariat expenses	(59.951)	(92.523)
Knud Jansen Lecturer	–	(25.000)
DKK	82.370	(117.523)

6. PROSTHETICS AND ORTHOTICS INTERNATIONAL

Advertising	145.619	137.043
Subscriptions	165.999	169.227
	311.618	306.270
Printing and mailing	(365.422)	(331.216)
Production editor	(16.524)	(28.124)
Meeting expenses	(14.256)	(12.172)
	(396.202)	(371.512)
DKK	(84.584)	(65.242)

7. PUBLICATIONS

Income from book and report sales	20.320	10.820
Membership directory	–	(97.216)
Reports Strathclyde	–	(19.622)
Above Knee Fitting, Report	(16.625)	–
DKK	3.695	(106.018)

8. INVESTMENT INCOME

Interest, bonds (note 11)	255.891	191.475
Interest, bank	62.454	25.833
	318.345	217.308
Dividends (note 11)	1.755	74.628
Maturity yield	4.495	2.792
Change in market value of securities	(66.224)	(85.303)
DKK	258.371	209.425

9. ADMINISTRATION EXPENSES

Executive board and officers:			
Travel and hotel		(272.017)	(392.056)
Meeting expenses		(27.835)	(50.792)
International Committee		(22.193)	–
	DKK	(322.045)	(442.848)
Secretariat, Copenhagen:			
Fees other organisations		(4.209)	(4.796)
Staff salaries		(283.190)	(277.728)
Labour tax		(12.446)	(16.648)
Data service		(7.587)	(7.747)
Business meeting expenses		(52.134)	(48.560)
Bank expenses		(7.710)	(8.066)
Postage		(73.056)	(77.302)
Telephone		(4.591)	(5.200)
Stationery printing		(15.301)	(22.642)
Office suppliers		(3.841)	(5.376)
Accountant		(30.500)	(28.400)
Book keeping		(23.690)	(24.700)
Sundries		6.226	(3.785)
Depreciation		(24.313)	(24.313)
		(536.342)	(555.263)
Administration expenses	DKK	(858.387)	(998.111)

10. OFFICE EQUIPMENT

Computer equipment (at cost)		95.347	95.347
Office equipment (at cost)		26.220	26.220
		121.567	121.567
Depreciation January 1, 1989		(72.941)	(48.629)
Depreciation for the year		(24.313)	(24.313)
		(97.254)	(72.942)
	DKK	24.313	48.625

11. SECURITIES

		Nominal value	Rate 31/12/90	Original cost	Value 31/12/90	Interest/ Dividends
Bonds						
9% Kred. Danmark 22.S.2007		3.118.000	91,25	2.904.572	2.845.175	255.891
	DKK	3.118.000		2.904.572	2.845.175	255.891
Shares						
Den Danske Bank		9.400	256,00	30.891	24.064	1.755
	DKK	9.400		30.891	24.064	1.755
	DKK	3.127.400		2.935.463	2.869.239	257.646

12. CONTINGENT LIABILITY

The association is involved in a court trial in connection with the World Congress 1980. The association might be liable to additional cost in this connection. The outcome is at present uncertain.

Prosthetics and Orthotics International, 1991, 15, 6–8

Executive Board Meeting

12 and 13 January, 1991

The following paragraphs summarise the major discussions and conclusions of the Executive Board Meeting held in Copenhagen in January. They are based on the draft Minute of that meeting which has yet to be approved by the Board.

International Committee/Executive Board Working Group

A report of the International Committee/Executive Board Working Group was presented to the Executive Board. It has subsequently been circulated to the International Committee through the National Member Societies. A major recommendation of the Working Group is to hold an interim meeting of International Committee Representatives and the Executive Board endorsed the need to hold such a meeting within the calendar year. The main points which would be discussed at this meeting would include the Report of the International Committee/Executive Board Working Group, ISPO Policy and the Slate of Nominations for the new Executive Board.

Standing Committee Chairmen and Task Officer Reports

Jorgen Kjølbye offered his resignation as Chairman of the Finance Committee and this was duly accepted by the Executive Board. It was agreed that Bent Ebskov (Denmark) should be invited to be Chairman of the Finance Committee. *(Honorary Secretary's note: B. Ebskov was subsequently approached and agreed to accept this appointment.)* The Honorary Treasurer presented the preliminary accounting for the year 1990 which anticipated an expenditure very close to budget. (*Honorary Secretary's note: the accounts for the year 1990 are published in this issue of the journal, page 3.*) The Honorary Treasurer presented the proposed budget for 1991 which was duly approved by the Executive Board. The membership fees for 1992 were set and it was agreed that they should remain at 450DKK for that year (175DKK for members from developing countries).

The Executive Board discussed anomalies in the constitution which had arisen as a result of previous amendments being made. They also discussed the position of Past Presidents on the Executive Board and the Protocol and Nominations Committee. A number of proposed amendments to the constitution were made by the Executive Board and these are printed in this issue of the journal on page 9.

Membership of the Society continued to grow in 1990 and now stands at 2,306 members, an increase of 34 over the previous year. This was particularly satisfying taking into consideration the fact that 1989 was a Congress year and showed an abnormally high growth in membership. The Honorary Secretary was in contact with Spain, Finland, France, Taiwan and Italy with regard the establishment of National Member Societies in these countries. Interest was also being shown in establishing National Member Societies in Indonesia, Turkey and Fiji as well as attempting to establish a Regional Society in Central America. The President Elect, together with the Immediate Past President and Honorary Secretary are preparing a new publicity leaflet for the Society.

The ISPO/INTERBOR Joint European Education Committee has prepared a questionnaire with regard to education and training in individual countries in the European Community. This has now been distributed to responsible authorities and individuals in different countries of the European Community and completed questionnaires are being received. In addition, the European Community, through the ERASMUS Bureau had given a small grant toward the preparation of a report for the European Community on the state of education and training in prosthetics and orthotics in Europe. A report to the European Community would be made by the end of 1991. John Hughes and Sepp Heim had attended a World Health Organisation (WHO) sponsored consultative meeting on training of personnel for orthopaedic technology in developing countries held in Alexandria, Egypt in June 1990. This meeting was productive and encompassed ISPO philosophy on education and training in developing countries as well as using ISPO reports as base documents for discussions. The meeting focused on the problems of poliomyelitis and a major outcome was a proposal to develop courses for prosthetics and orthotics assistants who would be trained to the same level as orthopaedic technologists but limited to either prosthetics or orthotics. As a result of the meeting in Alexandria a further meeting was held in Copenhagen prior to the Executive Board meeting and this was attended by representatives of the Society, WHO, Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ – the German overseas aid agency) and the Tanzania Training Centre for Orthopaedic Technologists (TATCOT). As a result, a proposal to establish a one-year course in lower limb orthotics technology is being put to WHO and the Tanzanian Ministry of Health for support. It was hoped that a similar proposal with regard to prosthetics could be made in the future. The proposal with regard to a pilot scheme for upgrading short course trained prosthetic/orthotic technicians is currently being explored with WHO.

The report of the workshop on CAD CAM in prosthetics and orthotics held in Seattle in 1988 has now been published. This issue of the journal contains a supplement on Wheelchairs and it is planned that the December issue will contain a supplement on Seating. A special edition of *Prosthetics and Orthotics International* on the Limb Deficient Child has been prepared with H. J. B. Day as editor and will be published in August.

The Concensus Conference on Amputation Surgery was held at the University of Strathclyde in Glasgow, Scotland from 1-5 October, 1990. The Conference critically examined literature related to amputation surgery published over the past 20 years with a view to identifying the best amputation techniques currently available. Literature on each level of amputation had been thoroughly scrutinised by a team comprising a surgeon and a prosthetist who reported their findings to the workshop. The reports and subsequent discussions had been of a very high standard and at present a report of that meeting is being prepared. Sponsorship for the meeting had been received from Otto Bock, U.S. Manufacturing Co., North Sea Plastics and L.I.C. and a number of participants had managed to find funding for their attendance from other sources. As a result of the Workshop it is the intention to hold courses on lower limb amputations and related prosthetics. Courses were planned for Tunisia, Indonesia and Yugoslavia. (*Secretary's note: Unfortunately, the course in Tunisia had to be cancelled due to the Gulf crisis: a new timing and venue are now being considered.*)

A proposal that the Society organise a workshop on the science and practice of socket fitting was being considered. The purpose of such a workshop would be to explore the following topics: the criteria for a good fit, related soft tissue mechanics and response, soft tissue tolerance and viability, application of current socket designs and design procedures including computerised systems, evaluation procedures and measurement techniques and educational requirements.

Progress was being made with the Professional Register. H. C. Thyregod reported that to date more than 1,300 replies had been received and entered in the Register. It was agreed that a protocol with regard to the use of the Register should be developed.

International Consultants

The Executive Board discussed the appointment of a Consultant to the Middle East and it was agreed that M. A. A. El Banna should be approached with regard to the possibility of his accepting this task. (*Secretary's note: Dr. El Banna had subsequently agreed to accept this task.*)

International Organisations

INTERBOR have established a Commission for the European Community. They hope to have a first meeting in April 1991 at which the Society would be represented. In addition, INTERBOR hope to organise a workshop related to socio-economic problems related to prosthetics and orthotics. It was agreed that the Society should participate in this workshop.

The development of working relations between the Society and WHO is progressing well. The possibility of establishing official relations with WHO is being explored.

The Society organised a session on prosthesis and orthotics at the Fifth European Conference of Rehabilitation International (RI) held in Dublin, Ireland, 20-25 May 1990. The Society also organised a session on prosthetics and orthotics at the Ninth Asia and Pacific Regional Conference of RI held in Beijing, China, 26-30 October, 1990. The Society has been invited to participate in the Seventh World Congress of RI to be held in Nairobi, Kenya, 7-11 September 1992. It was agreed that the Society should participate in this meeting by using its local members. A proposal will be prepared for the next Executive Board meeting.

The African Rehabilitation Institute (ARI) had invited the Society to become a member of its technical advisory committee. Arrangements are being made to find a suitable representative to attend the relevant meetings.

The next Internationaler-Verband der Ortopadie Schutechniker (IVO — the internationl organisation of shoemakers) course will be held in Amsterdam, 6-8 September 1991.

The Honorary Secretary attended two meetings in Vienna, organised by the UN in December 1990. The first was a consultative meeting of non-governmental organisations associated with the Centre for Social Development and Humanitarian Affairs (CSDHA) and the second a meeting of the International Council of Disability (ICOD), one of the consultant bodies of the UN. The Society was the only representative organisation present able to offer technical advice in prosthetics and orthotics. The Society is on the roster of consultants to the UN and full consultative status was currently being sought.

The Honorary Secretary reported that a letter had been received from the International Committee of the Red Cross (ICRC) indicating that the two ICRC hostages held in Lebanon had been released. ICRC thanked the Society for its interventions to various governments which had played a role in securing their release.

Congresses

Arrangements for the Seventh World Congress to be held in Chicago, U.S.A., 28 June-3 July 1992 are well underway. Detailed discussions on the programme had taken place in the International Congress Committee meeting held prior to the Executive Board meeting. A call for Papers will go out in June of this year and a full announcement will be made by December.

Bids to host the Eighth World Congress in 1995 were presented by Barry Markey and Valma Angliss on behalf of the Australian National Member Society and Hans Arendzen on behalf of the Netherlands National Member Society. The Executive Board discussed these bids in detail and after much deliberation decided that the next Congress would be held in Australia.

Conferences and Meetings

The President reported that both he and John Hughes had attended the European Conference on Rehabilitation Technology (ECART) held in the Netherlands, 5-8 November 1990. There had been 300 attendees and the meeting was quite successful. The organisers of the meeting agreed that a conference would be organised by ECART and held every three years. The next one will be held in France and the following one in Sweden. The President will keep in touch with the organisers of ECART in order that the Society may be aware of their future plans.

Acke Jernberger informed the Board of the difficulties in organising the Foot and Shoe Seminar due to be held in Jonkoping, Sweden, 10-13 June 1991. There was a dearth of contributions offered for this meeting. Should the desired number of contributions or their quality not be high enough, the meeting may have to be cancelled. (*Secretary's note: Since the Executive Board meeting it has been decided to cancel the Seminar on the Foot and Shoe due to lack of support.*)

Dundee '91 — Orthotics, an International Conference and Instructional Course will be held in Dundee, Scotland, 16-20 September 1991. This meeting is being held in collaboration with the Society.

Fellowships

Fellowships of the Society have been accorded to:

M. Schuch	U.S.A.
J. Michael	U.S.A.
T. Aoyama	Japan
Y. Ehara	Japan
F. Endo	Japan
H. Furukawa	Japan
Y. Hatsuyama	Japan
I. Kawamura	Japan
S. Morimoto	Japan
S. Nakajima	Japan
E. Sukizono	Japan
K. Takami	Japan
O. Tanaka	Japan
S. Tanaka	Japan
E. Tazawa	Japan
E. Watanabe	Japan
M. Fahrer	Australia

Fellowship Status

The Honorary Secretary reported that, as a result of the last International Committee Meeting, he had written to National Member Societies enquiring whether or not they felt that Fellowship status in the Society should be retained. Only five replies had been received, two for retention and two against and the remaining one against whilst suggesting that some form of recognition should be given to people of outstanding achievement within the Society. Because of the inconclusive findings it was agreed that this matter should be discussed again in the interim meeting of the International Committee Representatives.

Norman A. Jacobs
Honorary Secretary

Prosthetics and Orthotics International, 1991, 15, 9–10

Proposed amendments to the Constitution

The following amendments to ISPO's Constitution have been formulated by the Executive Board and will be discussed and voted on by the International Committee at their meeting which will be held in association with the World Congress in Chicago from 28th June–3rd July, 1992.

The proposed amendments to Clause 4.3.1 limit the number of Past Presidents on the Executive Board to one, the Immediate Past-President, and makes the editorial correction of changing the title "Treasurer" to "Honorary Treasurer".

The proposed amendments to Clauses 4.4.1, 4.4.6 and 6.1 make the editorial correction of changing the title "Treasurer" to "Honorary Treasurer".

The proposed amendment to Clause 4.4.5.1 makes the editorial correction of changing "He" to "The Honorary Secretary" in order to clarify the clause.

The proposed amendment to Clause 4.5.5 limits the number of Past-Presidents who sit on the Protocol and Nominations Committee.

It is also proposed that Clause 3.1.2 is removed from the present Constitution as its purpose is unclear and problems arising from distribution of publications have never arisen and are unlikely to arise.

Before the International Committee discusses these proposals, the Constitution requires that they be published to the International Committee and Members and Fellows for comment. Any such comments should be received by the Honorary Secretary before 1st February, 1992.

Original Clause	Proposed Clause
3.1.2 The ISPO may supply affiliated societies or groups with certain publications which in the opinion of the ISPO Secretariat are appropriate for distribution among those members of the society or group who are not Members or Fellows of ISPO. Such distribution will be made at the expense of the respective society or group, unless the society or group in question has given due notice to the Secretariat that it waives to receive certain publications to be further specified in the said notice.	DELETE
4.3.1 The Executive Board will consist of the President, the President-Elect, two Vice-Presidents, and four other Fellows of ISPO. The Honorary Secretary, the Treasurer, all Past-Presidents and all Standing Committee Chairmen join the Executive Board as non-voting members. The President, with majority approval of the Board, may appoint non-voting consultants to the Board.	**4.3.1** The Executive Board will consist of the President, the President-Elect, two Vice-Presidents, and four other Fellows of ISPO. The Honorary Secretary, the Honorary Treasurer, the Immediate Past-President and all Standing Committee Chairmen join the Executive Board as non-voting members. The President, with majority approval of the Board, may appoint non-voting consultants to the Board.
4.4.1 The officers shall be the President, the Immediate Past-President, the President-Elect, two Vice-Presidents, the Honorary Secretary and the Treasurer. The responsibilities of the Officers, the terms of office and the manner of election or appointment will be as specified in these By-laws.	**4.4.1** The officers shall be the President, the Immediate Past-President, the President-Elect, two Vice-Presidents, the Honorary Secretary and the Honorary Treasurer. The responsibilities of the Officers, the terms of office and the manner of election or appointment will be as specified in these By-laws.

(Cont.)

Original Clause	Proposed Clause
4.4.5.1 He shall be responsible for arrangements for all Executive Board and International Committee meetings including preparation of agenda and publication of these to all members of the Board or the International Committee. At least two months notice of such meetings shall be given where possible.	**4.4.5.1** The Honorary Secretary shall be responsible for arrangements for all Executive Board and International Committee meetings including preparation of agenda and publication of these to all members of the Board or the International Committee. At least two months notice of such meetings shall be given where possible.
4.4.6 The Treasurer (normally with the assistance of the Executive Officer) and under the direction of the President shall have general supervision of the fiscal affairs of the ISPO and shall be responsible for the keeping of accounts thereof and any other record required by law.	**4.4.6** The Honorary Treasurer (normally with the assistance of the Executive Officer) and under the direction of the President shall have general supervision of the fiscal affairs of the ISPO and shall be responsible for the keeping of accounts thereof and any other record required by law.
4.5.5 The Protocol and Nominations Committee shall comprise the President, the Past-Presidents, the President-Elect, two Fellows from the membership at large, the Honorary Secretary (ex officio).	**4.5.5** The Protocol and Nominations Committee shall comprise the President, the immediate Past-President, the President-Elect, two Fellows from the membership at large, the Honorary Secretary (ex officio) and up to two Past-Presidents nominated by the President.
6.1 The President, the Honorary Secretary and the Treasurer shall each have individual authority to commit the Society to obligations of funds within the budget approved by the Board in accordance with paragraph 4.5.4.2 of these By-laws. Standing Committee chairmen shall be entitled to commit funds made available to their committees by the Executive Board or obtained from outside sources.	**6.1** The President, the Honorary Secretary and the Honorary Treasurer shall each have individual authority to commit the Society to obligations of funds within the budget approved by the Board in accordance with paragraph 4.5.4.2 of these By-laws. Standing Committee chairman shall be entitled to commit funds made available to their committees by the Executive Board or obtained from outside sources.

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Clinical trial of a computer-aided system for orthopaedic shoe upper design

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Abstract

A trial has been conducted to produce the uppers for orthopaedic shoes using an existing commercial computer-aided design system. The aims of the trial were to confirm that a CAD system developed for the volume shoe trade (Shoemaster from Clarks Shoes) could be used for the upper design of orthopaedic shoes and to assess the contribution of professional shoe design on cosmesis and acceptability of these shoes. A small number of adult diabetic patients and children with foot deformities were selected, all of who had previously been prescribed and issued with special shoes. The existing lasts for these patients were digitised, and new styles developed on the CAD system over a 3D image of the last. Pattern pieces were cut automatically and the uppers closed. Lasting was done as normal at the two collaborating orthopaedic companies and the shoes supplied to the patients. The CAD system proved successful in coping with orthopaedic last shapes and shoe requirements. Professional design produced fashionable and cosmetically-pleasing styles within the constraints imposed by the underlying medical conditions.

Introduction

In orthopaedic footwear manufacture, advanced technology is very much less evident than in the volume shoe trade where it has been introduced widely over the past decade (Flutter, 1983). The introduction of computer-based techniques is however inevitable. Machining of foot shapes from digital information is demonstrated in Duncan and Mair (1983). Shape management technology for the generation and manipulation of last shapes is reported by Saunders et al. (1989). Investigations of surface modelling techniques for computer-representation of lasts have been conducted by Lord and Travis (1990). Staats and Kreichbaum (1989) have developed a system to design shoe inserts, in which the contours for a customised shoe insert are designed from the digitised information taken from a foot impression in a foam block. Several commercial companies claim to be using advanced technology in production. General issues raised by computer-aided design techniques are discussed in Lord and Jones (1989).

An ultimate goal for the application of advanced technology must be to automate the entire design process, from live shape scanning of the foot through to production of the last, the shoe upper and any shoe insert required. One stage in this chain, computer-aided design of the uppers, is already well developed for the volume shoe trade. Several commercial systems are available, and their use is being suggested for the orthopaedic industry. However doubt must exist initially about the suitability of these systems for this application.

The requirements for a CAD system in bespoke orthopaedic work are quite different from those in the volume trade. A range of lasts of abnormal shapes is encountered for patients with foot problems, and a question must be

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raised as to whether the commercial CAD system is sufficiently versatile to encompass this range. A second question can be asked about the benefits of using the CAD system. In the volume trade, the CAD system allows for rapid response to fashion, accurate pattern generation, and grading for size ranges. Of these, only accuracy of pattern generation initially appears to be of relevance to orthopaedic footwear, although CAD can be expected to make contributions to cosmesis through the availability of a range of styles on the system library.

The trial described below was conducted on the Shoemaster system* which has specially good capabilities for three-dimensional work. The trial was not intended to be a demonstration of how such a system might work in service. Rather, the more directed aims of the trial were to:

- confirm that an existing CAD system for shoe uppers is technically able to cope with orthopaedic shoe requirements, and
- assess the impact of professional design to produce fashionable and cosmetically-pleasing styles within the constraints imposed by the underlying medical conditions.

Procedure

Two research shoe designers from Shoemaster first visited the diabetic foot clinic at King's College Hospital and discussed with clinicians and patients their requirements for orthopaedic shoes. Constraints on style were that the final shoes would be suitable for the medical condition. The shoes would be mostly outdoor walking shoes with adequate instep fastening. The senior orthotist from each of the collaborating orthopaedic shoe companies (L.S.B. Orthopaedics Ltd. and J. C. Peacock & Sons Ltd.) selected subjects for the trial within the following constraints:-

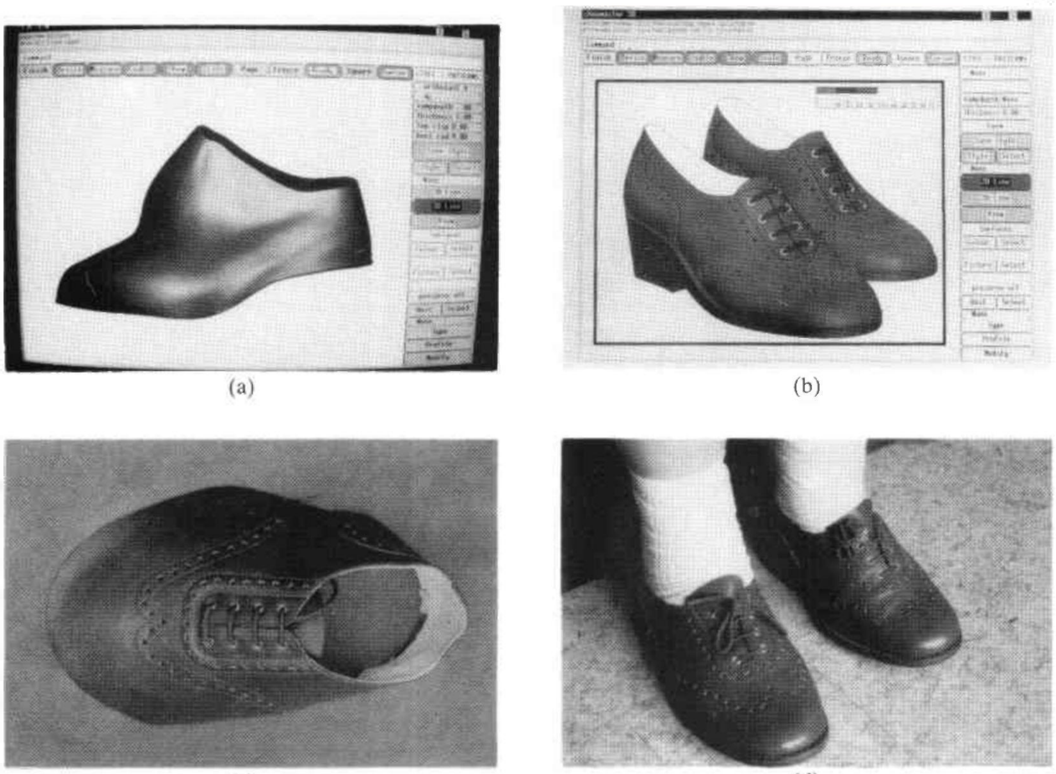
a. Subjects should recently have been issued successfully with special shoes for which recent lasts were available. For children, if there had been growth since the last pair of shoes, the feet should be remeasured and the existing lasts modified accordingly.
b. Patients selected for the trial should have the ability to help in the design of the new shoes and be well enough to attend the clinic for consultation and fittings.
c. Any internal orthoses or modifications to the shoes to accommodate external orthoses could be included.
d. L.S.B. Orthopaedics Ltd. were asked to identify adult patients with diabetic foot problems, and J. C. Peacock & Sons Ltd. were asked to identify children with foot problems typical of spina bifida.

The patients' lasts were sent for digitisation and the surface of each last was captured with a stylus digitiser. Any cradle or insert allowance was added to the last before digitisation. Lasts which had previously been modified with soft additions or which had fairly rough exteriors, thus making their surfaces unsuitable for the stylus, were vacuum draped with thin thermoplastic before application of the digitising probe.

The shoe designers brought the CAD system to the patients at the two clinics, where the designer and patient together sketched the shoe style on-screen over the three-dimensional view of one of their own lasts (Fig. 1a). The orthotist and orthopaedic last-maker were on hand for consultation. The preliminary designs produced on the computer in the clinic were later completed for that shoe. The final design was then mapped over the last shape for the other foot and the two shoes harmonised as a pair (Fig. 1b). For example, where there was one short foot, the shoe styling lines were managed in such a way as to make a proportioned *pair* of shoes.

After the design was completed, the 2D pattern pieces corresponding to the 3D image were engineered on-screen to include the correct cutting allowances etc. Leather was cut by computer controlled machinery and subsequent closing was performed in the factory. This included the use of automated decorative punching and stitching to achieve the special effects called for in the design. The closed uppers (Fig. 1c), together with the original lasts were dispatched to the orthopaedic shoe makers where the shoes were lasted and finished (Fig. 1d). The children's shoes were trial fitted before final finishing because of the possibility of growth. Shoes were issued to the patients with care being taken to assess fit and solicit reactions to cosmesis. Follow-up assessments were made to check that

*Shoemaster, Clarks Shoes, 40 High Street, Somerset, England BA16 0YA.



(a) (b) (c) (d)

Fig. 1. Example of a design process (a) screen view of an orthopaedic last. (b) completed design as a harmonised pair. (c) closed uppers (d) completed shoes.

the patient had been caused no problem by the footwear, for fit after wear, to seek the subjects subjective views on style and fit and to observe the state of the shoes after they had been worn.

Results and observations

The list of subjects, their background medical condition, the condition of their feet, and the CAD shoes made for them is shown in Table 1. The six children typically had very deformed feet with bulky midfoot areas, mostly resulting from spina bifida. In two cases orthoses extending above the ankle were worn. The four adult subjects were all diabetic; two pairs of feet were intact but prone to lesions, one man had undergone a forefoot amputation, and another lady had very sensitive and swollen feet following a recent operation since which she had not worn shoes at all.

All of the six children were successfully fitted. Both children and parents were very pleased with the 'high-street' appearance of the shoes. Three of the four adults were happy with the shoes provided. The fit was poor for the fourth adult, mostly due to lack of communication about the depth of special insole to be provided. This prevented the shoes being issued, but the patient was pleased with the style and at her request another attempt will be made to obtain a fit when a small lesion noted at the fitting visit has healed.

There were no major obstacles in the design or lasting process although several points which require attention emerged during consultation between the coordinators, the orthopaedic companies and the staff at Shoemaster. Detailed observations at the various stages of the process are given below.

The design process

Patients generally came with a clear idea of what they would like in broad terms of style and functional requirements. Two of the boys wanted their new shoes to look like trainers and

Table 1. Details of the patients on the trial, and the shoe styles developed for these patients

Subject	Sex	Age	Medical condition	Description of feet	Type of CAD shoes made
EMS	Female	75 yrs	Diabetes NIDDM (7 yrs)	L large dorsal tuberosity at 1st MP joint.	Yellow Derby style lace up.
WW	Female	69 yrs	Diabetes IDDM (33 yrs)	Neuropathy, unsteady gait.	Red lace ups. D buckle and U shaped closure.
KH	Female	64 yrs	Diabetes/oedema NIDDM (recent)	Surgery for equinus feet Buckled toes Hypersensitive feet.	Lace up. Reddish/brown with fancy laces.
DW	Male	52 yrs	Diabetes/ischaemia IDDM (10 yrs)	Amputation R toes 1–5 Amputation L 1st toe.	Black lace-ups.
DH	Female	14 yrs	Congenital left club foot with short leg and foot.	Equinus left foot, history of surgery.	Brown brogues with subject's punch design.
AH	Male	14 yrs	Congenital club feet.	History of surgery. Pronated feet.	Trainer type. Blue and yellow.
CE	Female	10 yrs	Congenital spina bifida, neuropathy and muscle wasting.	Needs to accommodate thermoplastic AFOs. Pronated feet.	Clarks "Hectik" purple suede shoes – T bar and buckle.
AG	Male	9 yrs	Congenital left club foot.	History of surgery, short left foot with varus forefoot.	Grey Clarks "Hardware" with yellow lace.
MP	Female	6 yrs	Congenital equinus feet.	Recent surgery, pronated and abducted feet.	Patent purple shoes with flower applique.
RP	Male	3 yrs	Congenital lymphoedema (Milroy's disease).	Feet very oedematous but with normal bone structure.	Black and white trainer type shoes.

one of them had come with a previously prepared coloured diagram (Fig. 2). The other children were encouraged to select from current Clarks styles which were displayed on example shoes. Three did this (Fig. 3). The designers brought a selection of patterned laces, fasteners, buckles etc. all of which could be used on the final shoes. They also suggested other features, such as a soft top edge used for the pair of laced walking shoes requested by one lady (Fig. 4). This proved to be a particularly beneficial exercise as the subjects had not previously considered the possibilities for these important styling additions.

The time taken with the designer and patient together for sketching one of the proposed shoes onto the computerised last shape was in the order of an hour to an hour and a half. For current Clarks styles, the pattern was called up from the library and mapped over the individual's last, which took far less time to achieve. The designers needed subsequent additional time to tidy the design, to map it over the other last and except for the existing styles, to do the essential pattern engineering (add lasting allowances etc.). The balancing of

Fig. 2. The design brought in as a free-hand sketch and magazine cut-out, and the corresponding design on the CAD system.

Fig. 3. A Clarks design was mapped over the orthopaedic lasts to produce these custom shoes.

Fig. 4. An example of a screen view and the completed shoe, showing a soft-top feature on a lady's walking shoe.

left and right shoe for odd-sized feet took some time.

Lasting the shoes

The orthopaedic companies undertook lasting the closed uppers and finishing the shoes which had been produced from large ranges of leathers available to Clarks. The special requirements and the working with some of these unusual leathers such as patent or soft leather did not present great problems although some of the standard orthopaedic procedures such as soaking puffs and stiffners and coating the lasts with talc were found not to be suitable. Adults' shoes made from fairly 'solid' leather were machine lasted and the soft leather adults' shoes and the children's shoes were hand lasted.

The lasting allowances were found to be even but could have been slightly greater to allow for the orthopaedic manufacturing processes. The uppers fitted snugly to the lasts indicating that the patterns were accurate. The linings were slightly short and had to be "pulled" to make sure they reached around the bottom of the last.

The design of the soles on the computer was an 'artists impression' but in reality, the orthopaedic shoemaker used his discretion and skill in finishing the shoes to give a balanced appearance and correct heel heights etc. This provided in general to be a successful technique.

Fitting and review of the shoes

No special problems with fit or wear related to the CAD system were noted. Very positive comments on cosmesis related to the *normality* of the appearance, whether for an original design or for the three cases where a Clarks style was adopted. The balancing of odd-sized shoes for some of the children was particularly successful, it being hard to determine on first inspection the larger foot.

In several cases the shoes were found on review to be wearing rather better than those normally supplied, and in one notable case, the shoes had withstood a period of three times normal without requiring the usual frequent toe-capping. This did not correlate with a heavier weight of leather being used.

On the whole, the CAD designs had more stitching than would normally be used. Some of the stitching was decorative. Care was taken to avoid stitching in locations which could be problematic, and this did not give rise to any problems of abrasion. Indeed the construction with more pieces contributed to the better holding of the shape over the forefoot, where the orthopaedic shoes were prone to crease on the uppers above the metatarsal break (Fig. 5).

Discussion

This trial has brought together the expertise from two quite different manufacturers of shoes in order to transfer knowledge both of new advanced techniques and of the cosmetic styling so readily developed on the system. In order to make use of the CAD system and the expertise of the designers, it was necessary for the orthopaedic side to appraise the fashion designers of the medical and functional constraints on style. Also the pattern engineers needed to appreciate the methods of lasting which would be employed, quite different for the one-off orthopaedic shoe than for the fashion shoe. This exercise in communication has produced very positive results.

Fig. 5. Comparison of the conventional orthopaedic shoe and trial shoe worn for a similar length of time. The trial shoe has held its shape better, which is thought to be a function of the styling.

In a service situation, a CAD system would not be efficiently employed in the manner of this trial. However this trial confirms that an existing CAD shoe upper system has the technical capability to design patterns for at least some categories of orthopaedic shoes. The system generated patterns which were a good fit to the orthopaedic lasts. Minor problems such as that which arose with lining allowances can easily be rectified in future. The system could also benefit from minor developments for orthopaedic use, for example to expedite balancing. These will be discussed fully in a separate detailed evaluation of the technical factors.

In the investigation of the contribution of artistic design into surgical shoes for the improvement of cosmesis it was noted how up-to-date fashion in colour, materials, patterns of stitchings and punchings and in the style of accessories such as lacings, fastenings and eyelets etc may be incorporated into special shoes. This was shared by both sexes. Several children wished to copy their friends in having trainer-style footwear, which is accepted by most state schools for everyday wear. The design input was not able to influence shape of the shoes which was pre-determined by the orthopaedic lasts. However, it was possible to use design style lines and other features to minimise abnormalities in shape and to suggest an alteration in the perceived appearance of the finished orthopaedic shoes. Good design also minimised the perceived differences between odd-sized feet.

The three cases where current Clarks designs were used are particularly significant. The psychological impact for children to have the same style as those available to their peer groups cannot be overestimated. This procedure of using a library style is the obvious mode of operation for a service scenario, and the CAD system showed that it was entirely feasible to map such a style over an individual last within a reasonable time scale and with good results in terms of the pattern pieces which were generated, attributable to the CAD system for these patients, who were typical of two major groups of consumers of orthopaedic shoes. Although none of the deformities were gross — such as would absolutely necessitate the taking of a cast — these feet could not be accommodated within normal shoes without problems. Extension of the findings to cover other major consumer groups, e.g. patients with arthritic conditions, is not automatic, although the team could see no technical reasons why this should not be possible. The functional requirements and medical problems should first be investigated to give the designers direction for possible styles, but the last shapes would not be grossly different to those already encountered.

It was noted by the orthopaedic shoemakers and by the patients that the leathers used in this trial were of a very high standard and had a large range of colours and textures. This is due to the large quantities a volume manufacturer is able to buy, and is one of the benefits which might be available from more centralised production of shoe uppers than is presently common in the UK. This incidental observation from the trial has cost-implications related to repair and replacement for the active patient.

Conclusion

This trial has indicated that the computer-aided design system tested has the capability to design for a range of orthopaedic shoe uppers. The system enabled current high-street styles to be duplicated for some patients, and for others very acceptable original styles were designed.

Acknowledgements

This project was partly supported by a development grant from the British Diabetic Association with medical collaboration from Dr. M. E. Edmonds of King's College Hospital, London. We acknowledge the considerable contributions of design engineers P. J. Smith, H. Bishop and E. Duffey and B. Holley of Clarks Shoes Ltd, B. Holback and S. Lloyd of L.S.B Orthopaedics Ltd. and C. Peacock and P. Charlton of J. C. Peacock and Son Ltd. (Director and Senior Orthotist of each company respectively). We particularly thank the Directors of Clarks Shoes for permission to use the Clarks styles.

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Cost-benefits in orthopaedic technology by using thermoplastics in developing countries

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Abstract

A case is made for using thermoplastics in prosthetics and orthotics when available in developing countries due to the cost-benefits that may accrue.

Introduction

The first commercially important plastic material is said to have been celluloid. The material was developed during the 1860's and was used among other things for billiard balls, as a substitute for ivory. As celluloid is easy to set on fire, a more temperature stable plastic material was sought. In 1907 Leo Baekeland received a patent for a plastic material consisting of phenol-formaldehyde resin compressed with wood-powder which two years later was marketed under the name of Bakelite. The material was very successful and is still manufactured with different types of fillers.

Rubber materials were developed much earlier than plastics. Thus natural rubber was commercially obtained from the tree Hevea Brasiliensis in the beginning of the nineteenth century. After Goodyear's finding that sulphur could vulcanize the rubber (patented in 1839), the material made its real breakthrough.

In 1910, the world production of plastics material was about ten thousand tons. When Bakelite was introduced to the world market in 1930, the production increased to one hundred thousand tons. Rubber production, at the same time, was about eight times greater. The use of plastic materials passed aluminium during the fifties, as seen in Figure 1 which shows consumption variation over a fifty year period (Terselius, 1988).

During the 1980's, the production volume of polymer materials passed the sum of the volume of metals in western Europe, USA and Japan.

As a consequence of the 1973/74 oil crisis with a shortage of raw materials and energy, a marked lowering of the production of plastic materials occurred. After that incident, the increase has become somewhat lower but the

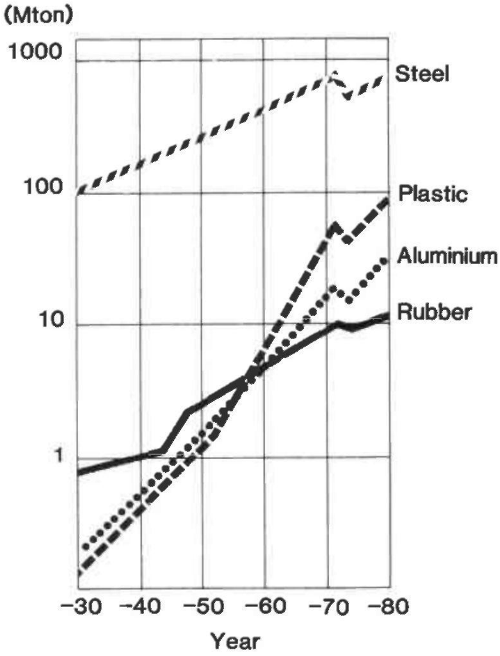

Fig. 1. Development of world consumption of selected materials.

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use of plastic materials in different designs has been increasing.

The case for thermoplastics

The 1973 oil crisis led to a high increase in oil prices and a lower volume increase for all design materials. As plastic materials consume lower energy when produced (Terselius, 1988), the process is often carried out at under 200° C, it will be favourably compared to metals in competitive situations (Fig. 2).

As shown in Table 1, the world production of plastic materials is about 50 million tons compared to that of rubber, which is about 12 million tons, with synthetic rubber accounting for twice as much as natural rubber (Terselius, 1988). It can also be seen that the most produced plastic materials in the world are polyethylene and PVC. The production of polypropylene is larger than the production of natural rubber. It could be noted that the plastic materials produced in large quantities have the same price as natural rubber or just slightly above it while a common material used in prosthetics and orthotics such as polyester is twice as expensive as common thermoplastic materials.

As prices of plastic materials now have become so competitive compared to the traditional metals and other materials, it has become common to use plastic materials also in developing countries especially in the construction and building industry. The common thermoplastic materials, polyethylene, PVC and polystyrene are therefore now also available in the developing countries. Other types of plastic materials are also becoming more and more available.

During the 1960's thermoplastic materials such as polyethylene and polypropylene became more commonly used in prosthetics and orthotics. The dropfoot brace was the first important application of thermoplastics in

Table 1. Plastic and rubber materials.

Polymer material	World Production (KTON/Year)	Price Index Per weight
Thermoplastics (1978)		
Polyethylene (PE)	17,900	1–1.2
PVC	12,100	1–1.3
Polystyrene (PS)	6,850	1.1–1.2
ABS	1,770	2.5
Polypropylene (PP)	5,150	1.1
Polyamide (PA)	430	3.5
Polycarbonate (PC)	225	4.1
Acrylic (PMMA)	90	2.3
Thermosetting Plastics (1978)		
Phenol-Plastics (PF)	400	1.4–1.7
Polyester (UP)	1,500	1.8–2.4
Urethane-Foam-Plastics (PUR)	2,400	Approx 4
Aminio-Plastics (UF, MF)	2,500	1.1–2
Epoxy (EP)	300	6–17
Total Plastics	Approx 50,000	
Rubber Materials (1983)		
Natural Rubber (NR)	4,000	1
Synthetic Rubber	8,200	1.1
Total Rubber	12,200	

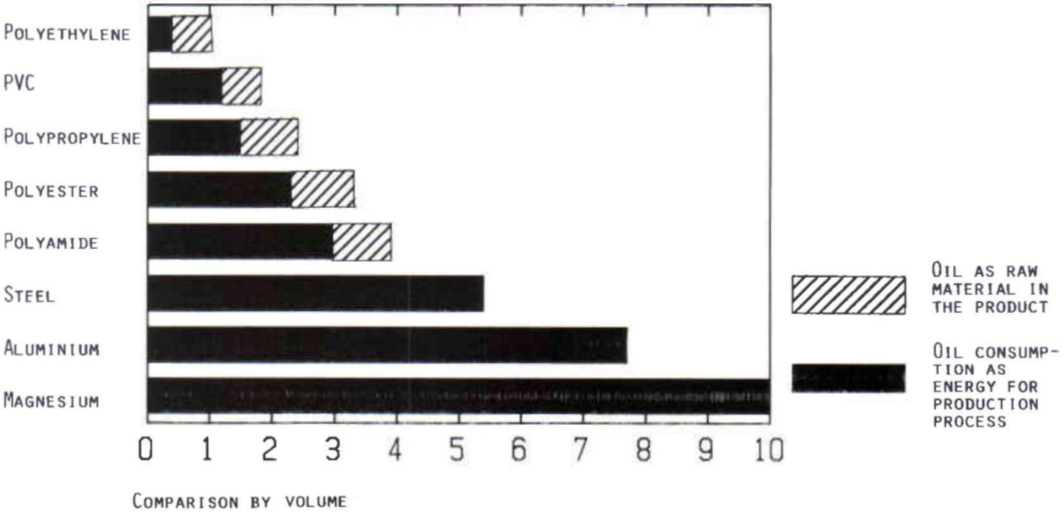

Fig. 2. The need for oil to produce different raw materials.

orthotics and is perhaps still the most produced orthopedic device made of thermoplastic material (Fig. 3). In addition thermoplastics are commonly used with metal joints to produce long-leg braces (knee-ankle-foot orthoses) and for the manufacture of spinal orthoses (Öberg, 1988).

During the 1970's, when new innovations in prosthetic sockets occurred more and more, thermoplastic materials were used instead of fibre-reinforced resins. Because of the properties of thermoplastic materials, the concept of flexible sockets could be introduced (Fig. 4). Another advantage of introducing thermoplastic materials in prosthetics was the possibility of making much lighter prostheses.

The concept of the ultralight below-knee prosthesis using polypropylene was developed at Moss Rehabilitation Hospital and at Rancho Los Amigos Hospital in USA (Quigley et al., 1977).

At Rancho Los Amigos Hospital, the evaluation of the ultralight prosthesis included measurement of oxygen consumption, comparing the difference between the ultralight prosthesis and the standard prosthesis in oxygen consumption per kg body weight per minute. The standard prosthesis required 21% more energy to use than the ultralight prosthesis. It should be noted that the standard prosthesis was twice as heavy as the ultralight one (Fig. 5).

Another clinical evaluation of an ultra-lightweight polypropylene below-knee prosthesis was completed at the National Centre for Training and Education in Prosthetics and Orthotics, University of Strathclyde (Convery et al., 1986). The study included the comparative evaluation of 24 patients with a standard prosthesis and an ultralight prosthesis which, on the average, had a reduced weight of 30%. They found two evident conclusions from this study:

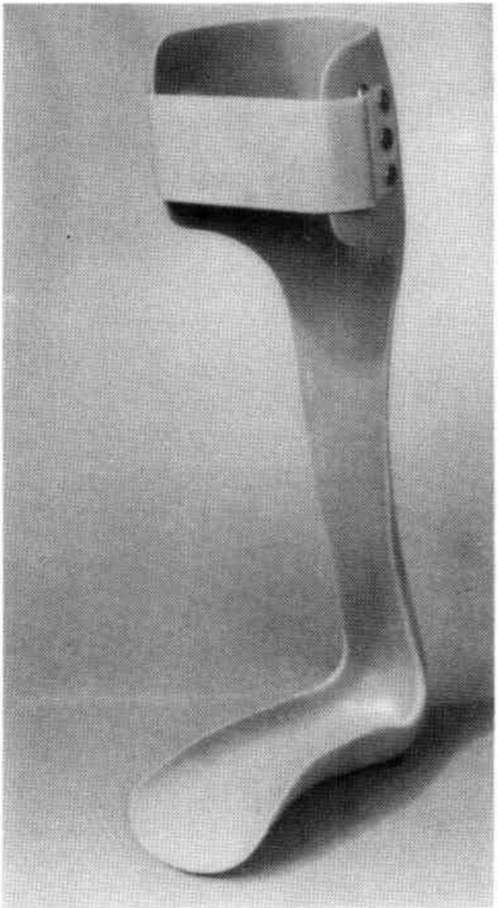

Fig. 3. Dropfoot brace (AFO) in a thermoplastic material.

Fig. 4. A flexible socket in thermoplastic with a rigid carbon fibre reinforced frame for an AK prosthesis.

- the amputees preferred the ultra-lightweight prosthesis
- the clinical team considered the ultra-lightweight prosthesis to be inferior to the resin-laminated one.

A review of orthopaedic technology in developing countries was carried out in 1988 by the author visiting sixteen different centres in Asia on behalf of WHO. A report on these visits was submitted to the WHO headquarters (Öberg, 1988).

Traditional western orthopaedic technology with, for example, laminated plastic sockets and wooden parts for the prosthesis structure were mostly observed. Aluminium and leather sockets were also utilized in a few centres. In an effort to impove effectiveness and quality, some centres were turning to the use of thermoplastics. Some centres in Africa already show good results in thermoplastic techniques for both prostheses and orthoses (Öberg and Goerdt, 1989).

For an inter-regional WHO meeting in Dakar, Senegal, centres throughout the developing world have been asked to give their view on the application of thermoplastic materials in orthotics and prosthetics in their own practice. Answers were obtained from fourteen different centres with almost comparable information which has been structured and set up in charts.

Six centres were from South America, six from Africa and finally only two from Asia. Looking at the results, it seems that they all are involved in the application of thermoplastics but it should be noted that all these centres, in varying amount, also are utilizing conventional techniques with polyester laminated sockets and wooden parts for prostheses as well as leather and steel for orthoses.

It is apparent from this review that the availability of thermoplastics around the world has increased. PVC and polyethylene was available in 93% of responding countries and polypropylene in 71% at the same time prices have decreased. Prices were regarded as low by 64% (9), medium by 29% (4) and high by 7% (1). The review is also a sign that the thermoplastic technology for these centres is fairly new as the complaints often indicated a lack of experience and equipment (Table 2). The technology therefore, still needs further development and also training and education is required for professional staff.

It is evident that there are considered to be numerous advantages in using thermoplastics in both prosthetics and orthotics when scanning the list (Table 3) recorded from the fourteen different centres.

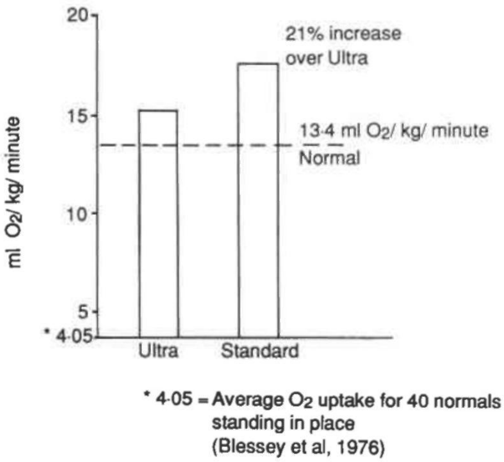

Fig. 5. Preliminary results of energy consumption (mlO_2/kg/min) when walking with BK prostheses (ultra-lightweight and Standard Trend from 4 patients, free cadence (Quigley et al., 1977).

Conclusions

It is to be concluded that appropriate materials in developing countries are not necessarily bamboo and leather or even wood.

When assessing materials, which would be appropriate for a certain developing country, major costs and benefits of the fitted appliances should be considered.

Table 2. Current Problems with Thermoplastics

High import restrictions	(4/14)
Heat from large surfaces (corsets)	(2/14)
Some skin irritations	(3/14)
Difficult to repair	(2/14)
Private exploitation	(3/14)
New technique with no experience	(6/14)

Table 3. The costs and benefits of Thermoplastics

Low weight	Good or better:
Durable	Fitting
Ease of fabrication	Function
Fast and efficient fabr	Comfort
Low cost materials	Cosmesis
Low cost appliances	Acceptance
Water resistance	Hygiene
Can be recycled	Tissue tolerance
Eaty to adjust	

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Wheelchair Supplement Foreword

The dominant themes of the ISPO Journal, Prosthetics and Orthotics International are, naturally, of prosthetic and orthotic subjects. The interests of ISPO, however, extend beyond these two subjects into other areas of Rehabilitation Engineering. This is not always reflected in the content of the Journal, possibly because workers in these areas submit to other journals and may be less productive of written articles. This issue and others attempt to redress this imbalance by including a series of papers concentrating on wheelchair and seating related topics. The papers result from 'Dundee 88', a conference on wheelchairs and seating.

Hopefully the appearance of such a concentration of wheelchair and seating papers will encourage people to submit papers on a wider range of topics and thus improve the under-developed nature of publication in Rehabilitation Engineering.

Tayside Rehabilitation Engineering Services at Dundee Limb Fitting Centre have a history of organising international conferences every three years on the "state of the art" of specific prosthetic and orthotic topics. The heat of a memorable ISPO World Congress in Copenhagen, 1986, spawned the idea of a departure of Dundee Conferences from prosthetic and orthotic topics to seating and wheelchairs. The established Dundee format was envisaged using invited experts to present the current state of clinical knowledge and practice. Workshop sessions and an exhibition would give opportunities for the exchange of information and expertise at a more practical and information level. There would be a social programme!

At the time, this was seen as a brave and possibly foolhardy, idea as there was no precedent for seating and wheelchair topics to attract an international audience for the planned period of one week. The spectre of a large auditorium sparsely populated by an audience of 20 to 30 invited speakers alone loomed large in the organisers' minds.

These fears proved to be groundless as the conference was fully subscribed with over 300 participants. I believe a useful and enjoyable week was had by all. Many lessons were learnt, not just from the words of wisdom of the speakers but also concerning the high level of interest and thirst for knowledge about seating and wheelchairs.

Prior to the conference, a publication had been planned, not simply based upon its proceedings, but written as a definitive work in its own right. This has resulted in two series of papers, one relating to wheelchairs which is presented in this issue and one relating to seating which is to be presented in a subsequent issue.

The wheelchair topics of this issue include mechanical and biomechanical treatments of wheelchair designs both of an occupant and attendant propelled nature. Interest in occupant propulsion is well established particularly for the athletic paraplegic. Attendant propulsion has been neglected in the past and consequently a review of the current UK provision of pushchairs and its limitations is included.

The practical considerations of wheelchairs are much neglected in their importance. The transportation by vehicle of wheelchair users in their wheelchairs is a daily occurence but is potentially very hazardous in the event of a crash. Rather than adopt the usual ostrich "head in the sand" appro ch to this problem, an Australian Standard has tackled it "head on" and is described in the final p per.

Geoffrey Bardsley
Guest Editor

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Biomechanics and the wheelchair

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Abstract

Wheelchair biomechanics involves the study of how a wheelchair user imparts power to the wheels to achieve mobility. Because a wheelchair can coast, power input need not be continuous, but each power strike can be followed by a period of recovery, with the stroking frequency depending on user preferences and the coasting characteristics of the wheelchair. The latter is described in terms of rolling resistance, wind resistance and the slope of the surface. From these three factors the power required to propel the wheelchair is determined, and must be matched by the power output of the user. The efficiency of propulsion is the ratio of this power output to the metabolic cost and is typically in the order of 5% in normal use.

The features required in a wheelchair depend upon user characteristics and intended activities. The ideal wheelchair for an individual will have the features that closely match these characteristics and activities. Thus prescription is not just choosing a wheelchair, but choosing the components of the wheelchair that best serve the intended purpose. In this paper, each component is examined for available options and how these options effect the performance of the wheelchair for the individual.

The components include wheels, tyres, castors, frames, bearings, materials, construction details, seats, backrests, armrests, foot and legrests, headrests, wheel locks, running brakes, handrims, levers, accessories, adjustments and detachable parts. Each component is considered in relation to performance characteristics including rolling resistance, versatility, weight, comfort, stability, maneouvrability, transfer, stowage, durability and maintenance. Where they exist, wheelchair standards are referred to as a source of information regarding these characteristics.

Introduction

In recent years many variations in wheelchair design and construction have become available. Thus for a given user there may be several options to choose from. Based on the physique of the user, the intended usage and the funds available, it should be possible to make an appropriate selection of design features and optional components that constitute the ideal wheelchair. The process of selection is one of matching features to requirements and to do this logically it is necessary to be knowledgeable in the relative merits of the various component designs and materials and to assess the capabilities of the user together with the environment and intended usage.

The first section of this paper deals with user capacity based on biomechanical studies. From this, it is possible to estimate the importance of seating position with respect to the hand rims and its effect on the stroke length and propulsion efficiency. Studies also include the work capacity of individuals and how this indicates performance in different environmental conditions such as hills, head winds and side slopes, and the influence of the balance of the wheelchair on propulsion effort. A discussion of the value of alternate drive systems such as cranks and levers is also included.

Correspondingly, the design and construction of the wheelchair and its component parts can have a marked effect on the performance, energy requirements and durability under various ambient conditions and use patterns. With a large variety of users, usage, and products, it is obvious

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that there is no one wheelchair for every user, but knowledge of the performance of each tyre of component part and each material can help in a logical selection. In many cases, the newly created International Standards Organisation's (ISO) Wheelchair Standards will disclose the necessary information. In other cases, some general rules can be presented to assist in decision making. This will be explored in the section on design characteristics.

Biomechanics

Much of the work on wheelchair biomechanics has been concerned with efficiency of propulsion, or in other words a measure of the effort required to do a certain amount of work. Unlike walking or running, the amount of work required to propel a wheelchair is readily measured and is dependent upon the rolling resistance of the wheelchair, the effect of ramps, side slopes and wind resistance. These will be discussed in the section on design characteristics. In the laboratory, this work can be simulated on a dynamometer.

Several things can be learned from efficiency experiments, such as the efficiency of a wheelchair compared to other means of mobility, and the effect of the design of the wheelchair on the efficiency. Brubaker et al., (1981) tested a number of athletes, and non-athletes, all wheelchair users to determine not only efficiency, but, also maximum work output. The maximum work output recorded on an athlete was 125 watts (W) with an efficiency of 13.9% (Table 1). This remarkable achievement is approximately 1/6 horsepower. For comparative purposes it is better to record the power per kilogram (kg) of body weight, and the maximum in this case was 1.88 W/kg with a 13.0% efficiency. The non-athletes, showed a much lower level and a correspondingly lower efficiency (Table 2). For a typical user on level ground, efficiencies as low as 3% are not unusual. Similar studies have shown that efficiency is higher for higher work loads and for lower speeds. A series of experiments using both normal and disabled persons showed that for a work rate of 0.4 W/kg efficiency averaged 9% at 3 kilometres per hour (km/h) and 10.3% at 2 km/h. For a work load of 0.2 W/kg and the same speed tests the efficiency dropped to 7.1% and 8.4% respectively. These studies give real evidence that for persons with a good arm function, gearing could be a real advantage to increase speed without increasing the effort.

It is interesting to compare the work output and efficiency with that obtained in pedalling. In preparation for a pedal powered flight from Crete to Tira, 118 km, athletes were tested by Nadel and Bussoleri (1988) for exercise bouts up to four hours duration. The results indicated a continuous work output of 5.25 W/kg with efficiencies ranging from 18% to 34%.

Of practical interest to the wheelchair user, is how can the design improve efficiency. Studies by Engel and Hildebrand (1974) showed that levers moved back and forth to drive the wheels could increase the efficiency compared to handrims.

Similar studies by Brattgard et al., (1973) indicated that cranks also were more efficient than handrims. Unfortunately there are practical difficulties associated with both levers and cranks which increase cost, weight and complexity. The crank studies were conducted using bicycle type cranks mounted in front of the user — a juxtaposition that is mechanically difficult and socially undesirable for the user. Typical lever systems rely on connecting rods to drive the wheels. This causes difficulties in manoeuvring and in starting, particularly on slopes. Brubaker

Table 1. Maximum performance data for national calibre wheelchair athletes.

Subject	Disability	Sex	Wt (kg)	VO_2 (Rest)	VO_2 (Max)	Energy Cost (watts)	Power Output (watts)	Power Output (watts/kg)	Efficiency (%)
KJ	T10	F	49.9	0.19	1.31	394.8	41.7	0.84	10.6
GL	SB	F	35.4	0.17	1.33	408.9	34.7	0.98	8.5
CB	T3	F	44.9	0.18	1.41	443.6	41.0	0.91	9.5
SR	T12	F	57.2	0.20	1.68	521.7	62.6	1.09	12.0
GM	T10	M	80.0	0.28	2.84	902.0	125.0	1.56	13.9
FM	C5-7	M	80.6	0.28	0.95	234.4	30.8	0.38	13.1
FY	C6+	M	58.1	0.20	0.95	255.6	29.2	0.50	11.4
BH	Polio	M	59.1	0.21	2.55	824.9	111.1	1.88	13.0

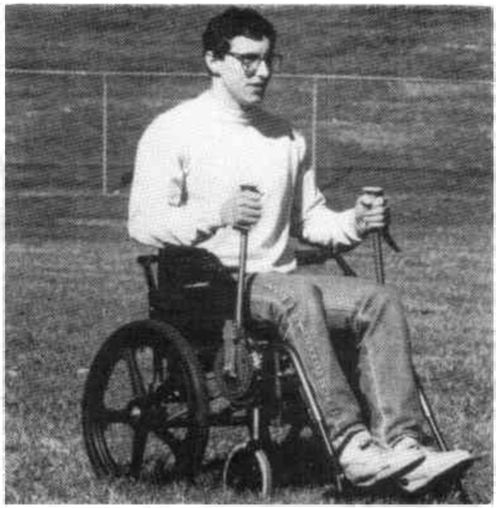

Fig. 1. Experimental lever drive system fitted to a commercial wheelchair. A clutch is operated on each stroke by inward force on the lever. allowing the user to stroke forward, reverse or apply brakes as required.

and McLaurin designed a single acting lever system that overcame these problems (Fig. 1) and subsequent tests with single acting levers, that is levers that produce a driving force in only one direction, were tested. The results of the testing indicated an increase in efficiency as compared with rims (Fig. 2).

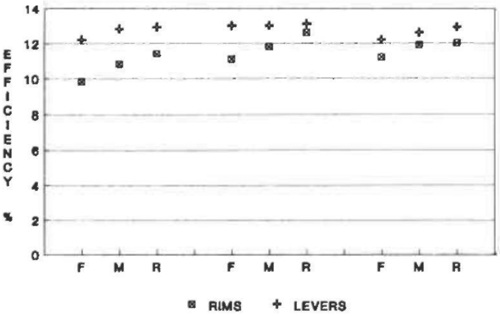

Fig. 2. Results of testing rims and levers at the same speed and load for nine seat positions. Note that the efficiency for levers was nearly independent of seat position and somewhat greater than that for handrims.

It was stated earlier, that gearing could increase efficiency. Another consideration is seat position with respect to the handrims or the levers. Studies (Brubaker et al., 1984) with six normal and six disabled subjects at the University of Virginia (UVA) indicated that moving the seat with respect to the axle has a considerable effect using handrims, but little effect using levers. It should be noted that the conventional position with the backrest directly above the axle is not ideal for maximum efficiency.

Table 2. Wheelchair performance data for non-athletes using the wheelchair dynamometer.

Subject	Lesion Level	Relative Load (watts/kg)	Absolute Load (watts)	Efficiency (%)	Heart Rate	Speed (kmph)	VO_2 Max (l/min)
LM (F)	L1-2	0.52	27.3	10.0	171		1.29
WW (M)	T4	0.48	40.9	7.9	150		1.46
JG (M)		0.81	72.9	8.0		3.5	2.96*
CB (F)		0.20	10.9	5.1	130	3.0	0.88
		0.25	13.6	5.5	139	3.0	1.02
		0.40	21.7	6.8	150	3.0	1.12
AS (F)		0.20	10.4	6.4	115	3.0	0.67
		0.25	13.0	6.8	118	3.0	0.79
		0.40	20.7	7.8	144	3.0	1.01
RC (M)		0.20	16.4	7.8	90	3.0	0.98
		0.25	20.5	9.3	95	3.0	1.01
		0.40	32.7	0.3	110	3.0	1.29
DM (M)		0.20	15.0	7.5	89	3.0	0.87
		0.25	18.8	7.8	103	3.0	1.00
		0.40	30.0	8.9	107	3.0	1.29
TS (M)		0.20	20.9	9.0	77	3.0	1.01
		0.25	26.1	10.4	87	3.0	1.08
		0.40	41.8	10.5	104	3.0	1.50

* Maximum Value

The reason that seat position affects efficiency is found in the mechanics of the arm during the power stroke and recovery. The optimum seating position is primarily dependent upon the position of the shoulder joint with respect to the axle, and the dimensions of the arm segments. This determines the geometry of the joint position and the range of motion of the muscles used in propulsion.

Arm motion has been studied at the UVA on the wheelchair dynamometer previously referred to, with the addition of a set of four instrumented wands attached to the wrist, near the elbow, near the shoulder and at the base of the cervical spine. Each wand is attached to three potentiometers which continuously record the angle of the wand in space and its length from its reference base to the body attachment (Fig. 3). A computer programme converts this information to the position of the neck, shoulder, elbow and wrist with respect to the wheelchair rim.

Data from this arm position instrumentation can be plotted to illustrate motion during a propulsion stroke (Fig. 4) along with the associated input torque. It is interesting to note that only a part of the forward motion is effective in driving the rim. During the early part of the stroke, the hand is accelerating to the speed of the rim. After rim contact, the hand continues to accelerate, providing input torque to the rim. After releasing the rim, the hand begins to decelerate before beginning the return stroke to the starting position.

The pattern of the stroke varies with seat position (Fig. 5). When the seat is high, the stroke is shorter because the hand cannot reach as far down the rim. When the seat is forward, the stroke acts on the forward part of the rim, and when the seat is to the rear it acts over the top of the rim. A low seat allows a longer stroke over a large section of the rim. This means that the force input can be lower than for a high seat where the energy must be applied in a shorter time. However, for the higher seat position and shorter stroke, a higher frequency is possible since the time for the power stroke is less and the return to the starting position is shorter.

The return or recovery stroke is worth considering. Even though no energy is imparted to the rim at this time, energy is required to move the arm backwards to the starting position. With a low seat, the elbow must be flexed for this action. With a high seat, this flexion is minimized, thus reducing the required energy. It has been postulated that one reason why levers are more efficient than handrims, is that the weight of the hand and forearm rests on the lever and hence less energy is needed for the return stroke.

Experienced and athletic wheelchair users often use a low stroke frequency when cruising. In

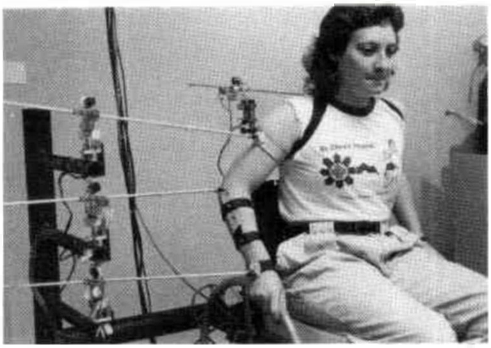

Fig. 3. A subject on the dynamometer with wands attached to the arm and base of the cervical spine. Three potentiometers on each wand provide information from which the shoulder, elbow and wrist positions are determined.

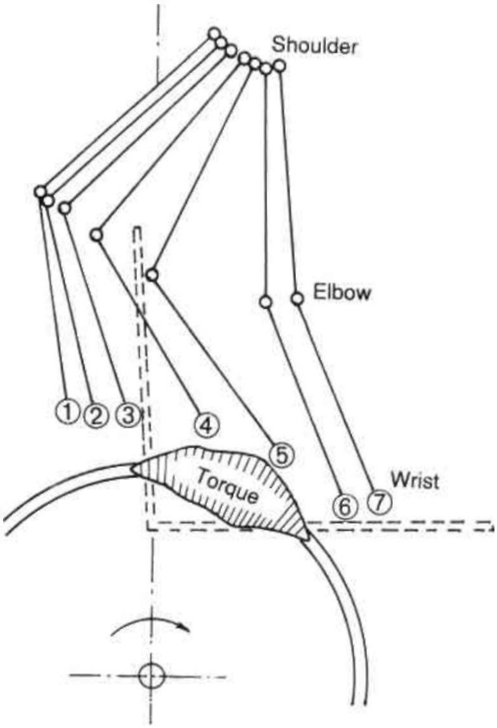

Fig. 4. Stick diagram of a typical forward stroke for a seat in the position shown. The segments are depicted at 1/10s intervals. Note that torque is applied during only three of these seconds.

this case, greater force is applied to the handrim during the power stroke, thus accelerating the wheelchair to a greater extent. This allows the wheelchair to coast further before the next power stroke is required. Under these conditions the return stroke is much like a leisurely pendulum swing, requiring little effort. With low frequency stroking a wheelchair with low rolling resistance becomes increasingly important so that it does not slow down appreciably between strokes. Measurements of the torque input and the associated variations in wheelchair speed illustrate the changing speed during power input and recovery (Fig. 6).

For racing, handrims are smaller in diameter. For a 27in (524mm) wheel they may be as small as 15in (381mm) or even 12in (305mm). The reason is to gain mechanical advantage or more correctly speed advantage. Pushing on a 15in handrim on a 27in wheel at 5 kmph will produce a speed of $5 \times \frac{27}{15}$, or 9 kmph. Since wheelchair athletes may travel at a speed of up to 25 kmph and there is a practical limit to the speed of muscle contraction (approximately 10 × muscle length per second) it is not difficult to see the importance of small diameter handrims for racing.

In order to reach small diameter handrims, the seat must be lowered, and the wheels cambered (tilted inwards at the top) to permit the arms to reach comfortably over the wheels.

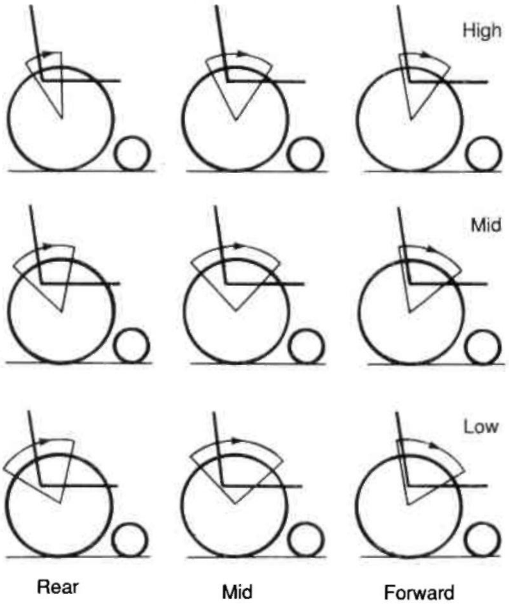

Fig. 5. The grasp and release position during the forward stroke is shown for nine seat positions.

When stroking the handrims at higher speeds, there is insufficient time for the hand to grasp the rim. Typically the stroke force is applied by friction between the rim and the thumb and forefinger which raises large callouses. A friction surface on the rim will reduce the pressure required to drive the rim forward. A friction surface also makes propulsion easier for those with weak or impaired hands. Unfortunately the friction surface is too effective when the handrims are used for braking, causing severe skin damage when braking from high speed or down a steep hill.

The cross-section shape and size of the handrim can also have some effect. Typically a handrim is made from round tubing about 16mm in diameter. Smaller diameters are difficult to grip while larger diameters, up to 25mm may be more comfortable. A wheelchair user in California designed and used a rim with an egg-shaped cross-section with an average diameter of about 25mm (Farey, personal communication). Based on this experience, the UVA laboratory tested several, about this size, and although the results were scientifically inconclusive, the subjectively preferred shape was elliptical in section with the long axis canted at about 20° to the vertical, very similar to Farey's design. The 20° angulation could be either inwards or outwards, according to preference.

Tanaka (1982) and Brubaker and Ross (1988) have studied muscle activity during simulated propulsion using electromyography. Surface electrodes placed at or near the motor points of arm and shoulder muscles recorded the muscle activity associated with each part of the stroke.

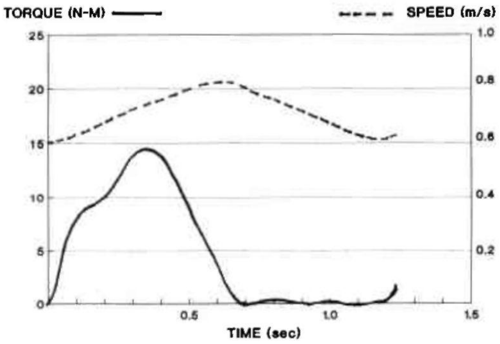

Fig. 6. A typical torque curve for one complete cycle showing the resulting speed (upper curve) of the wheelchair. At higher speeds, the curve becomes much higher and acts for a shorter period of time.

The marked difference between the muscle activity of a person with normal arm musculature during a lever drive exercise for three seat positions (Fig. 7) is typical of the variations that occur and for this reason, EMG studies have not yielded very useful information to date.

Design characteristics

With an understanding of the human factors in wheelchair mobility, it should be possible to assemble a wheelchair that best suits an individual, but first it is necessary to examine the technical characteristics of the various components and their influence on the overall design. Having assessed the ability of users to perform work, it is worth examining the wheelchair to determine the work required. There are four factors which govern the work required to propel a wheelchair: the surface over which it is rolling, the slope, wind, and the rolling resistance of the wheelchair. Only the latter is a function of the wheelchair design, but the design can have an effect on performance with respect to the three environmental factors. For example, some tyres may be suitable for hard pavement but not for grass. Tyres are the single most important factor in determining rolling resistance on level terrain.

The total effort required to propel a wheelchair is the sum of the rolling resistance, the wind effect and the slope. On a firm level surface the rolling resistance may be as low as 6 newtons (N) or as high as 40 N, depending on tyres and alignment. The wind effect can be considerable. Coe (1979) at NASA Langley studied this in a low speed wind tunnel. With a drag coefficient considerably worse than a flat plate, a wheelchair will require a force of 12 N to overcome a head wind of 20 kmph. Doubling the wind speed would increase the drag force four times. The largest force to overcome is that due to gravity on ramps and hills. For a wheelchair and occupant weighing 100 kg the force required to mount a ramp of 1 in 12 gradient is

$$\frac{100}{12}\text{ kg or }\frac{100 \times g}{12}\text{ N}$$

$$= 82\text{ N}$$

where g = acceleration due to gravity

The total force required to move up the ramp must additionally overcome rolling resistance (say approximately 6 N) and wind resistance (typically 12 N).

$$\text{Total force} = (82 + 6 + 12)\text{ N}$$

$$= 100\text{ N}$$

The power required to generate this force depends upon speed. At 1 metre per second (m/s) this would be 100 W.

An average user with a maximum output of 30 W would be reduced to

$$1 \times \frac{30}{100}\text{ or 0.3 m/s (1 kmph)}$$

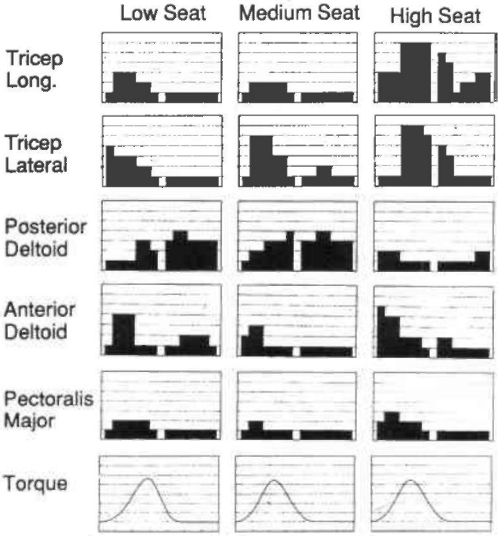

Fig. 7. Muscle activity of a person with normal arm function during a typical stroke cycle at three seat heights.

Wheels and tyres

The rolling resistance of tyres on a smooth firm surface has been measured at the UVA on a treadmill. For these tests, a special cart was constructed, to which a pair of wheels could be mounted. The cart was tethered to a force transducer to measure the pulling force with different loads and treadmill speeds (Fig. 8). From these tests it was concluded that the pulling force varied directly with the weight, but was nearly independent of speed. The tests also indicated a marked difference in the rolling resistance of different types of tyres. For example a high pressure pneumatic tyre required only one quarter of the pulling force of the solid grey rubber tyres which were in common use throughout the United States. The wheel

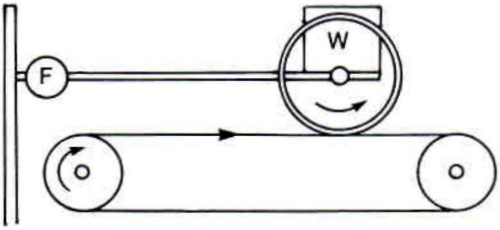

Fig. 8. Diagram of a test cart on a powered treadmill for measuring rolling resistance. The cart allows misalignment of the wheels to measure the effect of toe-in and toe-out.

alignment could also be adjusted on the cart. From this, it was learned that camber up to 10° (tilting the top of the wheels inward) has no significant effect on rolling resistance. Toe-in or toe-out, however, resulted in a serious increase in the pulling force. Only one or two degrees misalignment could double the required force (Fig. 9).

Studies regarding the rolling resistance of tyres on grass or other off-pavement surfaces are difficult to perform since there is no practical way to characterise or simulate such surfaces. However some indication may be inferred by test results on carpet. Ordinary tightly woven carpet can double the rolling resistance while shag carpet can cause an increase of five fold. On soft ground or sand, it can be assumed that wide tyres will roll more easily than narrow tyres. The diameter of the tyres also has a significant effect. As a general rule, the rolling resistance is inversely proportional to the diameter. Thus a castor wheel which is one third the diameter of a drive wheel, will have about three times the rolling resistance if it is carrying the same load. For this reason it is important to maintain as much weight as is practical and safe on the main wheels of a wheelchair.

Although pneumatic tyres are preferable to solid rubber from a standpoint of rolling resistance, comfort and weight, recent research has shown that this may change in the near future. Synthetic tyres are superior in wear resistance and not subject to flats from slow leakage or punctures. Kauzlarich et al. (1988) has been working on tyre design for some time and has concluded that a synthetic tyre can be designed to be much more durable, cheaper, lighter and with a rolling resistance comparable to pneumatics. Synthetic tyres are particularly advantageous for castor wheels where the small air volume causes difficulties in maintaining air pressure. Thacker et al. (1988) is currently examining ride quality of tyres with various spring suspension systems, so that even if synthetic tyres do not provide as smooth a ride, springs may more than compensate for this deficit.

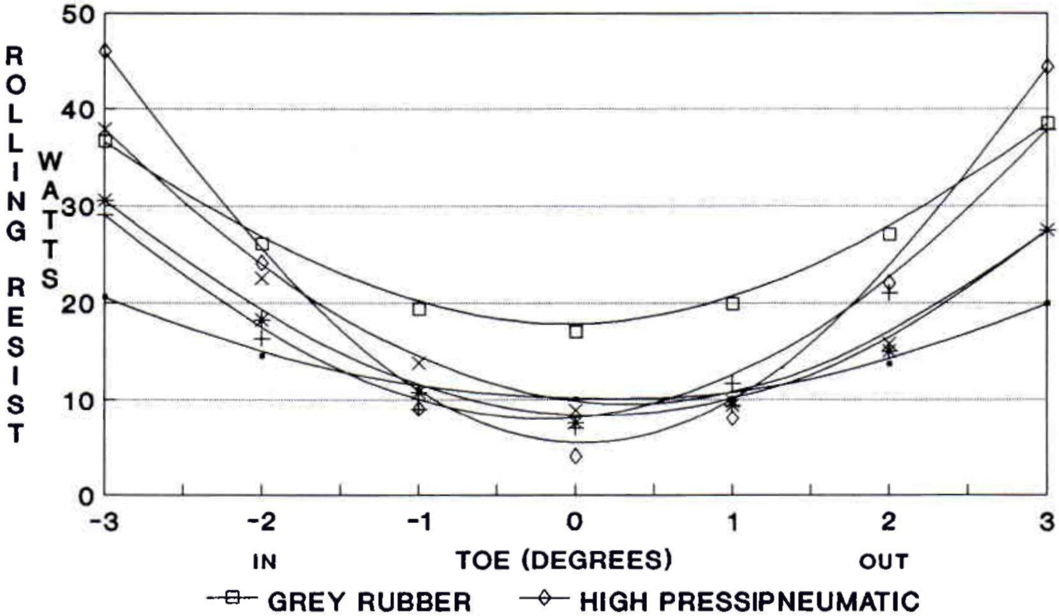

Fig. 9. Rolling resistance of several wheelchair tyres with changes in alignment. The rolling resistance is highly dependent on the type of tyre and the alignment. The tests were run at 4 kmph with a laden weight of 100.2 kg.

Tyres or springs which absorb shock also decrease the stress on the frame, axles and wheels. Two types of wheels are in common use, those with wire spokes and "mag" wheels where the rims, spokes and hubs are moulded or cast in one piece from lightweight metal or reinforced plastic. Using up-to-date bicycle technology, wire spoked wheels are the lightest available. Unlike the rear wheel of a bicycle, no torque is transmitted from the hub to the rim, unless hub brakes are installed. Thus straight radial spokes, instead of cross laced spokes may be used, resulting in a stiffer wheel. Also because a wheelchair wheel may experience heavy side loads when turning, the hubs may be wider to put the spokes at a more advantageous angle. In spite of being light but strong, wire spoked wheels are subject to damage, and once a few spokes are loosened, the wheel quickly deteriorates. For this reason the "mag" wheels are becoming more popular and in normal use should last indefinitely, requiring no maintenance. However, they are considerably heavier and usually more flexible. Common materials include aluminium, but most are made from nylon or similar plastic which has been reinforced with short fibres of glass or a similar material. Carbon fibre (graphite) is one of the strongest reinforcing materials and one wheel of Swedish design uses this in the tubular spokes to decrease the weight while maintaining strength. Recent innovations in bicycle technology suggest that composite construction may be used for disc wheels, utilizing a combination of reinforced plastic with a core component of foam or honeycomb.

No consideration of wheel design is complete without including the axle and bearings. Traditional ball bearings roll between cones, one outer and one inner screwed onto the axle. Although inexpensive, these bearings require frequent adjustment, which if not maintained can result in a loose wheel and damage to the bearings. Most modern wheelchairs use sealed ball bearings, which never require adjustment, and are sealed against the entry of dust and dirt. In normal use they should last the life of the wheelchair. Axles are a highly stressed part of a wheelchair, particularly when bouncing over kerbs. The strength is determined by the size, the material and the presence or absence of stress-raisers, such as threads at critical locations. Since the axle stress is not easily determined, the only safeguard for the buyer is the test results disclosed in Wheelchair Standard ISO 7176/8 strength tests, which applies to the wheelchair as a whole. Two types of axles are generally available, the fixed or bolt on type and the quick release type. The latter offers advantages in removal for stowage in a car, in changing to different wheels for off-pavement use or for changing to a different axle position.

Handrims

The material from which a handrim is made is an important factor. Farey's rims and those used for the testing at UVA were made of plywood which has a pleasant feel and appearance, but is much too expensive in production quantities. Also, it is generally believed that the rim should be metal to dissipate heat while braking, although no formal test results are available. Metal handrims may be aluminium, chrome plated steel, or stainless steel. The latter is to be preferred. Aluminium rims are easily scratched and dented, even when anodized. Without anodizing they leave black marks on the hands and clothing. Chrome plated steel rims are sturdy and have an excellent finish, but there is a danger that some of the plating may fail and start to peel off. This results in razor sharp bits of plating curling up off the surface which pose a severe threat to any skin that comes into contact. NASA (Fig. 10) has produced composite handrims for experimental purposes. These are light and strong, with a smooth surface, and can be produced in any colour. Vinyl and other plastics are used as a coating over metal rims to increase friction. These too, can be produced in any desired colour. Softer foam covers have also been introduced, to increase gripping friction and to avoid injury to insensitive hands. Although these have not been

Fig. 10. An experimental wheelchair with the seat, side panels and hand rims produced by NASA. The panels have a foam core with skins of Kevlar and graphite impregnated with epoxy resin.

used extensively, the approach has considerable merit when compared with the pegs and knobs that are often used to aid propulsion for persons with quadriplegia.

Castors

Although some wheelchairs, particularly outdoor lever drive models and racing wheelchairs have steerable wheels, most wheelchairs use castors because they allow motion in any direction. The basic castor consists of a wheel, an axle, a fork and a stem. Wheels are available in several sizes. A smaller wheel (5in or 125mm in diameter) may be quite satisfactory for indoor use, except on thick carpet. For outside use, even on pavement, the small castor produces a jolting ride and is easily caught up on bumps and holes. Even larger wheels (8in, 200mm) can fall into cracks such as those found on elevators and for this reason and others, wide tyres are preferred over narrow ones. Pneumatic tyres, although they roll easily and provide cushioning are difficult to keep inflated. To ensure easy rolling, the wheel and axle must have ball or roller bearings. Since the axle is close to the ground, bearing seals are needed to exclude water and dirt.

The fork is one part of the wheelchair that is easily damaged, particularly where it attaches to the stem. Damage occurs from impact with obstacles such as kerbs and pot-holes. The frame adjacent to the castor is also one of the highly stressed points. The castor stem is one of the most critical parts of a wheelchair. If the stem is not vertical, but is tipped to the left, then the wheelchair will turn to the left when coasting. This is the primary reason for poor tracking characteristics. Also if the stem is tipped forward at the top, the effective trail is reduced. The trail is the distance from the ground contact of the tyre to the spot where the axis of the stem would intersect the ground. With a vertical stem, this dimension is the distance of the axle behind the stem (Fig. 11). The trail is an important parameter. A long trail makes turning easier but causes the castor wheel to sweep through a greater arc, taking up more room in the area of the footrests. A long trail also means that castor flutter is less likely to occur. Castor flutter or shimmy is not only annoying and energy consuming, but can be very dangerous. The rolling resistance of a castor can multiply ten times or more when fluttering. Thus, when coasting down a gradient, the onset of flutter acts like a brake which can, and often does, cause the occupant to be thrown forward out of the wheelchair.

In addition to the trail, castor flutter is influenced by the weight of the tyre. A large heavy tyre is more prone to flutter than a light one, and can be much more troublesome when it does. However a tyre with a wide tread or a dual tread can help to damp flutter, or increase the speed at which flutter will occur. Damping can also be produced by mechanical friction or hydraulic action at the stem. The latter has the advantage of incurring little resistance at low rotation speeds, with high resistance at high rotation speed of the castor at the stem. At this time, however, no hydraulic units are available commercially for this purpose. Several mechanical friction devices have been demonstrated and some manufacturers will supply them. One design developed at UVA consists of a pair of nesting cones surrounding the castor stem inside the castor housing. A compression spring forces them together, causing friction on the stem which effectively prevents flutter for normal wheelchair speeds. It has been tested for a million cycles without appreciable wear. The device does result in increased turning force, but this is small compared to that induced by friction of the tyre.

The Frame

Although some generalization can be made regarding the materials and construction of the frame, the overall design should depend upon the characteristics of the user. A simple lightweight frame may be ideal for an athletic active user, but be quite unsuitable for someone requiring a

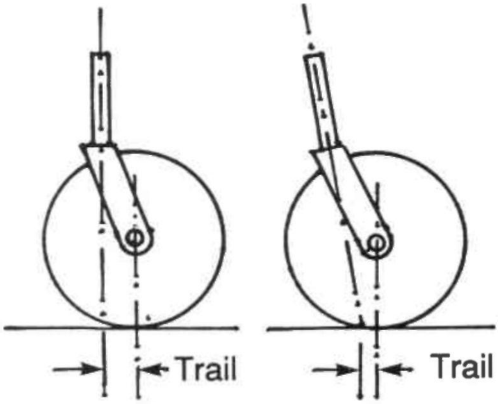

Fig. 11. Diagram of a castor illustrating how the trail is reduced if the stem is tipped off the vertical. This increases the incidence of castor flutter or shimmy.

reclining back support or elevating leg supports and who usually travels with a carer or companion. The simple lightweight frame, which has become popular in recent years, may be either folding or non-folding. The non-folding style has advantages in saving weight while maintaining durability. With quick release axles, stowing in an automobile is possible, particularly if the back is low or folding. For most purposes a folding frame is desired, not only for vehicular travel, but for space saving within a home. Most wheelchairs use the "X" frame or "camp stool" type of folding mechanism. One of the problems with this mechanism is that the frame alignment and hence the wheel alignment can change with persons of different weight, causing increased rolling resistance. Flexibility is often built into the frames to allow all four wheels to contact the ground in spite of irregularities. Apart from alignment problems, many users prefer the feel of a rigid frame and some folding models are designed with this in mind. Frames that must support elevating legrests and reclining backrests will be considerably heavier than the simpler styles. In these models, the ease and security of the adjustments should be checked, but of prime importance is the geometry of the mechanism. Since the hinges for the back or legrests do not correspond with the human hip and knee joints, the wheelchair may not fit the occupant correctly when leg or back adjustments are made. This should be checked before prescription. The back is particularly critical since lowering the back with the occupant seated can cause shear forces between the person and the chair.

The common frame material for wheelchairs is mild steel tubing. It is both inexpensive and durable, but can be heavy. In order to save weight many manufacturers have been offering other materials, such as alloy steels and aluminium alloys which can reduce the weight by half with comparable strength, but perhaps double the cost. Aluminium alloy frames even with an anodized finish are easily scratched and soon lose their pristine appearance. Steel frames may be chrome plated, which provides a durable easy to clean finish, or painted. Paint which can be applied to aluminium or steel is also easily scratched, although the choice of colours has an appeal to many users. Stainless steel, although expensive, offers a most durable finish although weight saving compared with mild steel is minimal. Recently plastic frames have appeared on the marketplace. These have advantages with colour that is integral with the material, and since no finishing is required, cost savings can be realized. Even though the plastics include reinforcing fibres, the result is a more flexible frame than those made from steel. Also some designs include a myriad of webs and stiffeners between which dirt can collect. Frames made from reinforced plastic tubing have also been used. These are strong and light but joining the tubes has been a problem. As in the automobile industry, the use of plastics in wheelchairs is likely to increase but to use plastic effectively in frames, conventional design must be abandoned. As new designs suitable for plastics emerge we can expect to see the benefits of low cost, colourful and functional frames from plastic and composite materials.

Seating

Seating in a wheelchair for comfort, postural control and skin care is a separate topic. In this paper only two aspects will be discussed, adjustments and material properties of the seat and backrest.

For many years, the common material for both seat and backrest has been reinforced vinyl fabric. It is moisture proof, abrasion resistant and easily cleaned. It also exhibits undesirable properties such as stretching. The moisture-proof nature of the material prevents it from "breathing" and hence it is hot and uncomfortable in warm weather. This drawback is less important in the seat where a cushion may be used, but here the stretching quality causes the seat to sag, altering the support characteristics and creating excessive pressure under the trochanters.

Fortunately many models are now available with sturdy fabrics woven from synthetic fibres such as "Cordura", a material used in back-packs and similar applications. These fabrics can be fitted much more tightly than vinyls, resulting in a flatter seat. Because of the benefits of a flat seat that does not stretch, there is a current trend towards solid seats. With good design and appropriate materials, a solid seat adds little in weight, increases structural integrity, allows folding and should never need replacing. Solid seats have been made from plywood, which tends to be heavy, from reinforced plastics, and from composites, such as panels with skins of epoxy impregnated graphite and/or Kevlar bonded to a core of foam or honeycomb (Fig. 10).

Seating adjustments are becoming more common in wheelchair design, but it should be remembered that any adjustment carries a penalty in cost, weight and strength. Common adjustments are seatback angle and seatback height. Seat angle and seat height adjustments are also available, but perhaps the most important adjustment is to allow the centre of gravity of the user to be positioned correctly with respect to the main wheels. This is commonly done by providing a selection of axle positions. This not only changes the wheelbase, possibly resulting in castor interference, but may change the axis of the castor stem, requiring an adjustment in that mounting bracket. These problems can be avoided if the seat can move with respect to the sub-frame or chassis. Some experimental models have been built that allow the user to adjust the seat forward and backward while seated. This can be especially useful while ascending slopes, where the weight should be forward to prevent backward tipping.

Footrests

From the designer's viewpoint, footrests are a very difficult challenge. They may be subject to high loads from a user in extensor spasm, and from inadvertent impact with kerbs, doorways and other obstacles. They should be independently adjustable and easily removed for easy transfer in and out of the wheelchair. For a tall person, seated at a normal height, they must be positioned well forward to keep the feet above the floor and to avoid interference with the castors. If leg elevation is required, the problems are further increased.

Many lightweight sport type wheelchairs have used a bar or pair of bars joining the two sides of the frame in front of the castors. This is light and strong, but does not allow individual adjustment and removal for transfer. The most popular means for removal is the swing away type which can also be lifted off when the lock is released. The foot plate may be cast aluminium, reinforced plastic or tubular construction, the latter being light and strong, but providing less support for the foot. The foot plate is usually hinged to fold upwards, adding a little more weight and complexity. The foot plate is usually attached to the supporting tube by a friction clamp. This can be advantageous during impact, allowing the structure to slip rather than break.

Individually adjustable, and contemporary swing-away footrests require that the feet be placed some distance apart, depending on the width of the wheelchair and the size of the foot plates. For many persons it is more desirable to place the feet together. Apart from postural and aesthetic reasons, this tends to avoid spacial interference with the castors. This foot position presents no problem with one piece footrests, but requires clever geometry in the structure and hinging of individually adjustable models, something which has yet to appear on the market. As a general rule, the selection of an appropriate footrest should be based on the *simplest* design that can accommodate the needs of the user.

Armrests

Much of the discussion on footrests applies to armrests. Fixed armrests, as an integral part of the frame are the lightest and strongest solution but provide no adjustment and may interfere with transfer. The ISO Wheelchair Standards state that an armrest must be strong enough and secure enough to allow lifting of the wheelchair and occupant *or* release before lifting so that there is no danger of releasing during the lift. Traditional removable armrests which plug into vertical sockets must therefore have very secure latches or none at all. Many wheelchairs now have armrests of a different design, the most common being one that is pivoted at the rear so that it swings upwards and backwards to avoid interference when transferring. This type of armrest avoids the lifting problem and avoids the inconvenience of a separate part which can be dropped or misplaced. A possible disadvantage is the absence of a skirt to prevent clothing from contacting the wheel. The common adjustment to armrests is for height which may not yet be available in the pivoting type. The type of armrest may also be dictated by the need for a lap tray which is usually fastened to the armrests.

Brakes

Most manual wheelchairs are equipped with brakes for parking. Braking to a stop or while descending a slope is accomplished by friction to the handrim. Some wheelchairs are equipped with dynamic brakes that can be used for both functions. These are of special value to those with impaired hand function or where hills are frequently encountered. Using the hands for braking on a hill can cause skin damage and is inadvisable for those with insensitive skin. Most persons with quadriplegia have little or no ability

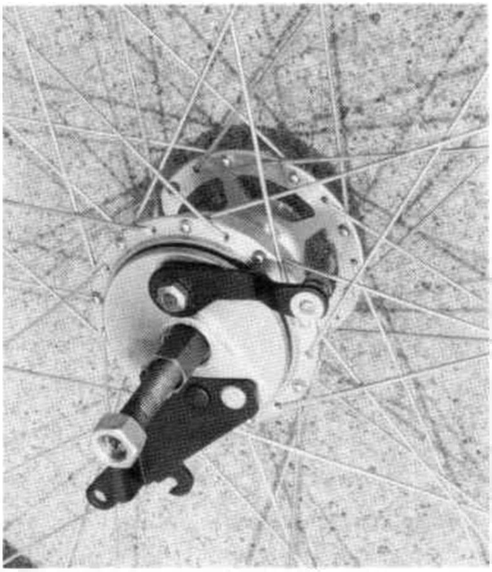

Fig. 12. A drum type dynamic brake for use on a wheelchair. Note that, as in a bicycle the spokes must be cross laced.

to descend slopes safely unless the wheelchair is equipped with dynamic brakes. A survey conducted by UVA and the Paralyzed Veterans of America indicated that most users wanted such brakes, but they are not yet available in the United States.

Dynamic brakes are available in Europe in two different types, one which operates on the tyre, and one which operates on the wheel hub. The latter is preferable since it will work with a flat or worn tyre, but it does carry a penalty in weight and cost. Hub brakes (Fig. 12) are usually drum type adapted from bicycle technology. Disc type brakes at the hub or calipers acting on the rim have also been used. Studies at UVA have shown that the calipers do not provide as smooth control as the drum type and may be affected by rain. The effectiveness and the operating force for wheel locks is included in Wheelchair Standard ISO 7176/3.

Chassis configuration

Although a wheelchair can be considered to be the sum of its parts, the way in which these parts are assembled can profoundly affect the performance of the wheelchair. Wheelchairs with rear castors and large front wheels may be easier to propel for some persons, and be easier to manoeuvre in a restricted space. Rear castored vehicles, including wheelchairs, are directionally unstable. When coasting, any slight force or obstacle that tends to change the direction of motion will automatically result in a violent swerve. This is easily demonstrated by pushing and releasing the wheelchair, empty or loaded. A front castored vehicle is directionally stable, and will quickly recover from any force or obstacle that tends to divert it from a straight path. Either model may have misalignment of the castor stem or other imperfections that cause tracking irregularities, but the basic principle of castor position and stability is universally applicable. The reason lies not in the castors themselves but in the position of the centre of gravity with respect to the wheels with fixed axles (in this instance with the main wheels). If the mass is behind the main wheels, then if these wheels are caused to turn a little from the direction of motion, they are pushed further into the turn by the inertia of the mass. A mass in front of the main wheels (i.e. front castors) will tend to pull the wheels out of the turns. Some wheelchairs have been built with the centre of gravity located directly over the main wheels, with one castor in front and one behind. Such wheelchairs have neutral stability with no tendency towards stable or unstable direction (Fig. 13).

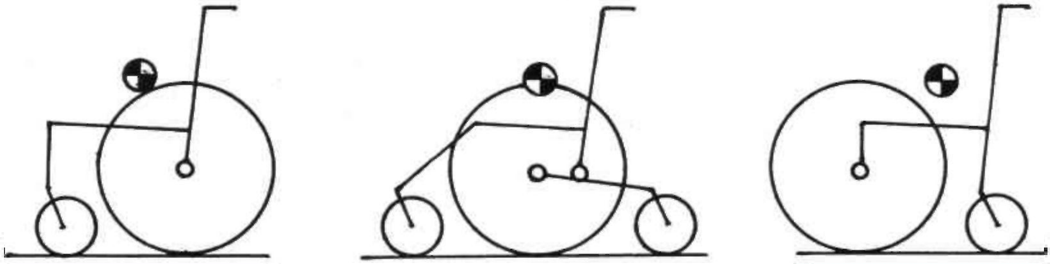

Fig. 13. The directional stability of a wheelchair depends upon the position of the centre of gravity with respect to the main wheels.

Directional stability is not important at low speeds, except when traversing a side slope. Most outside paved surfaces have side slopes for drainage. A front castored wheelchair will tend to turn downhill on a side slope. A rear castored wheelchair tends to turn uphill and a wheelchair with the weight directly over the main wheels will tend to go straight. This tendency to turn on a side slope depends upon the distance of the centre of gravity in front of or behind the axis of the main wheels and the angle of the slope. The turning moment is the product of the distance of the centre of gravity from the axis of the main wheels and the component of gravity that is parallel to the slope (Fig. 14). This turning moment must be countered by increased effort on one handrim and decreased effort or braking on the other handrim. The net result is an increased energy requirement which depends upon the width the wheels are apart as well as the previously mentioned factors. A side slope of as little as 2° may require double the energy for propulsion. Ergonomic testing however, has shown that the metabolic energy may not be doubled since one arm is doing the work, and for low energy levels, one arm is more efficient than two, since it is working more closely to optimum conditions.

A centre of gravity close to the main wheels may be an advantage in other situations, and may actually be safer. It has been shown that rolling resistance is decreased as more weight is transferred to the main wheels. Taking weight off the castor wheels also reduces the turning force at low speeds and makes "wheelies" (balancing on rear wheels) easier and safer. Wheelies are useful on rough terrain, are essential for mounting kerbs, and are a useful postural variation. They are accomplished by a combination of backward leaning while accelerating forward with the handrims. With a centre of gravity slightly forward from the main wheels, the mass rises only very slightly and little effort is required. With the centre of gravity far forward of the main wheels the tilt angle is great and the mass rises considerably, and a strong effort is needed to accomplish the task. Too much effort can result in tipping over completely.

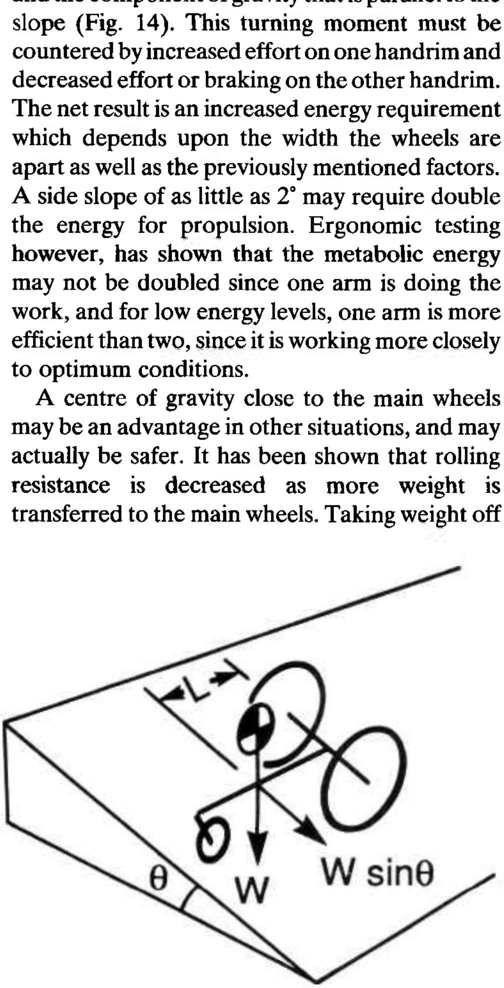

Fig. 14. A diagram showing the forces acting on a wheelchair traversing a side slope. With a front castored wheelchair the downhill turning moment is the product of the distance of the centre of gravity forward of the main wheels and the total weight multiplied by the sine of the angle of slope.

Anti-tipping bars (wheelie bars) are a common accessory but are seldom used. They are an obvious safety device if one is to practise wheelies, but unless properly positioned they can be a nuisance. For example, if they are positioned to allow tipping with the castors high enough to clear a kerb, they will catch on the kerb when dropping off the kerb in the wheelie position.

Wheelchair Selection

It is true that some wheelchairs are better built than others, have a better finish, are aesthetically more pleasing or perhaps are more fashionable. For structural integrity the purchaser can review the ISO test results which should be disclosed by the manufacturer (ISO 7176/8). This also applies to other ISO standards covering static stability, (7176/1) efficiency of brakes (7176/3) overall dimension, mass and turning space (7176/5) and seating dimensions (7176/7). It is hoped that this article by providing general information regarding specific details of construction, materials and configuration will be of assistance when choosing a wheelchair with the best characteristics for a particular person and unexpected usage. Unfortunately, a checklist, matching personal requirements with functional features becomes rather confusing. For example a light, elderly person may need a lightweight wheelchair, but with the reliability of solid tyres and the extra weight of elevating legrests. It is suggested that, when choosing a wheelchair, the characteristics and needs of the user be listed and matched as closely as possible, feature by feature with available models, considering the options and accessories.

Particular mention should be made concerning weight, since this is one of the most popular

Table 3. Component weight comparisons for two wheelchairs

Component	Weight in kg (lb)	
	Conventional	Sports
Frame	6.7 (14.7)	3.8 (8.3)
Seat	1.0 (2.1)	0.3 (0.6)
Back	1.0 (2.2)	0.3 (0.6)
Armrests	1.9 (4.2)	–
Footrests	2.7 (5.9)	0.8 (1.8)
Wheels, Tyres, Rims	5.1 (11.2)	3.8 (8.3)
Axles & Hardware	0.4 (0.9)	1.1 (2.5)
Castors	2.0 (4.5)	1.8 (4.0)
Wheel Locks	0.5 (1.2)	0.5 (1.0)
Total	21.3 (46.9)	12.4 (27.1)

features of newer models. Certainly there is little place for the 25 to 30 kg models that were common a few years ago when similar durability is now available for 15 to 20 kg. However it should be remembered that the total weight may be quite different from the stripped down weight. Each time a new accessory or different feature is added, the total weight may be increased (Table 3). For steady-going on level ground weight may not make much difference. The type of tyre and wheel alignment is more important. When going uphill, weight can make a significant difference, but since the occupant may weigh three or four times as much as the wheelchair, an increase of 10% in the wheelchair weight will result in only about a 3% increase in the propulsion effort. Weight plays a very significant role, however, when the wheelchair must be lifted for stowage in an automobile, or hauled up a flight of steps even when empty.

Finally, after many years of conservancy the wheelchair industry is responding with an impressive variety of design alternatives and innovations. The effectiveness of these in helping the people that use them will depend on how wisely the choice is made.

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The design of attendant propelled wheelchairs

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Abstract
The attendant operated wheelchair is propelled by applying forces to handles at the rear of the chair. There are no published data to justify the design of pushing handles on existing wheelchairs. In Dundee, studies of pushing have been conducted in order to obtain subjective preferences for location and design of handles and an understanding of biomechanical factors associated with wheelchair pushing.

Preferred positions for handles have been found to be in the region of 0.75 of shoulder height, 1.14 times shoulder width although deviations of ±5% in these values are still rated as acceptable. The preferred positions do not correspond to minimum levels of resultant force or with lowest levels of moment in any of the upper body joints. Moments occurring at the lower back are not substantially affected by handle position. The biomechanical analysis so far has not revealed why some handle positions are more comfortable for pushing than others. Further study, involving calculation of resultant moments (rather than just sagittal plane moments) at these joints and at the lower body joints, is a next step in attempting to find the indicators of discomfort.

Transferring a patient from or to a wheelchair can be a difficult operation with risks of accidents to the patient through falling and risks to the attendant of strain, particularly to the back. Current footrests on wheelchairs are a major source of the problems during transfer. A new approach to footrest design is described which solves these difficulties by using a footrest that lowers onto the floor. This has other attractive features such as providing good stability and restraint of the chair during transfer. The armrests are also discussed since they have a role to play where patients can assist themselves during transfer but have the potential for being an obstruction when patients need to be lifted from wheelchairs.

The ease of pushing and manoeuvring, the difficulties caused by obstacles such as carpet edges and lift entrances, the operation of the brakes, and the position of the pushing handles are all important aspects of chairs used for transporting patients. The wheels, particularly the wheel diameter, tyre compressibility and castor trail, are determinants of the mobility aspects. However, the position of the wheels in relation to the centre of gravity and whether the castors are at the front or rear must also be considered. The brakes, as well as being effective, should be easy to apply and not too affected by wear. A prototype wheelchair is described which incorporates design features suggested by research into the above considerations.

Introduction

Attendant propelled wheelchairs are used indoors and outdoors by domestic users, and also in hospitals and institutions to transport patients who are too unwell to walk. Those used in the domestic environment are intended to carry disabled or elderly occupants who are not capable of using a self-propelled wheelchair, and who may not be able to operate or cannot afford a powered chair. Attendants are usually a family member or close friend of the occupant. Many attendants, such as husbands or wives, are elderly themselves and

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may be enfeebled, others are parents of disabled children and adults. They frequently experience difficulties with pushing and manoeuvring their wheelchairs — especially outdoors — and with transferring the occupant into and out of the chairs. In the hospital setting wheelchairs are used by nursing staff to transport patients locally within the ward area and by porters to carry them to the various hospital departments for treatment. This again involves transferring patients into and out of the chairs, a process which can be very arduous for the attendants, who will be moving many patients each day. It is important then that attendant propelled wheelchairs are designed for making propulsion and general operation as easy as possible for the operator by minimising the physical demands placed on the attendants.

This paper commences by reviewing studies of the biomechanics of attendant propulsion, a subject which has not been investigated in great detail compared with self-propulsion. It will then discuss the two principal concerns for the attendant — patient transfer and mobility of the wheelchair — and the design features which relate to them. A review of the different types of attendant wheelchairs in domestic and hospital use will be given at the end of the paper, to illustrate the range and application of the models available.

Biomechanics of attendant propulsion

In order for a wheelchair to be driven, steered and manoeuvred with ease, its rolling resistance and turning resistance should be low and the mode of propulsion should be optimised biomechanically to maximise comfortable operation of the chair. A biomechanical study of attendant propulsion of wheelchairs is in many respects less complex than that for occupant propulsion; there is no need to investigate effects of users' disabilities, different methods of driving the chair (such as handrim or lever propulsion), or influences of the relative position of the occupant and the drive handle on the efficiency of propulsion. The attendant wheelchair simply incorporates handles located at the rear of the chair which are used to control all propulsion and manoeuvring operations. The position of the handles (their height, separation and shape) affects the load distribution on the wheels while driving the chair, the posture and comfort of the attendant and the biomechanics of propulsion. These points will be discussed below. Biomechanical studies to date have only included pushing. Pulling, turning and other manoeuvring have not yet been investigated. The discussions in this section are based on work reported by Abel (1988).

Mechanics of propulsion

Figure 1 shows a horizontal force F_h being applied to a wheelchair in order to maintain its speed against a rolling resistance R. The rolling resistance occurs at ground level, i.e. at the contact region between the wheel surface and the ground over which it is travelling. If a horizontal pushing force is applied to the handles at a height above ground level a turning moment will be generated which transfers a proportion of the weight of the occupant and chair from the rear wheels to the front wheels. This will make the chair more difficult to push if the rolling resistance for the front wheels is greater than that for the rear wheels. The magnitude of this effect is shown below to be small.

For wheelchair wheels running on hard surfaces, rolling resistance is approximately proportional to the vertical load carried by the wheel (Frank and Abel, 1990), the ratio of the resistance force to the vertical loading being the coefficient of rolling resistance μ . Referring again to Figure 1, the ratio of F_h required to propel a vehicle with handles at a height h above the ground, to the horizontal force F_g (=R), which would be required at ground level, may be shown to be equal to $L/(L-h\,\delta\,\mu)$, where $\delta\mu$ is the difference between the coefficients of rolling resistance of the front and rear wheels (i.e. $\mu_f-\mu_r$) and L is the wheelbase. This ratio is unity for most models of attendant propelled wheelchairs designed for use in hospitals since they use the same types of front and rear wheel (i.e. $\delta\mu=0$). For outdoor attendant propelled wheelchairs, which have front castors that are smaller than the rear fixed wheels, typical values for L, h, μ_f and μ_r are 0.4m, 0.95m, 0.045 and 0.02 respectively. These figures give a value if F_h/F_g of about 1.05, i.e. the attendant propelled wheelchair requires about 5% more force than an equivalent self-propelled wheelchair with the same weight distribution on the wheels, to propel it at constant speed. It has been found that the preferred height for pushing handles is about 0.73 to 0.74 of shoulder height (0.6 of stature) which, for the middle 90th percentile of the British male and female populations, is in the range 0.90 to 1.10m (Abel, 1988). The change in the ratio F_h/F_g over this range (which includes the heights of handles on most current attendant wheelchairs), is only about 1%. This effectively means that handle height can be selected for user comfort without affecting the magnitude of the force required to push the chair.

Efficiency of pushing

When attendants push against the handles of wheelchairs, and other similar vehicles, they do not push directly forwards — there is a tendency also to lean on the handles, producing a resultant force which is inclined downwards. Leaning on the handles adds to the vertical loading on the wheels and therefore also the rolling resistance. An efficiency of propulsion E_α may be defined as the ratio of the force required to push the wheelchair forwards when the resultant force, F, is inclined at an angle α downwards (Fig. 1), to the force required to push the chair when the resultant force F_h is horizontal (in the direction of motion). E_α may alternatively be expressed as 1-μtanα, assuming all four wheels to have the same coefficient of rolling resistance, an assumption which has little effect on the calculation and is anyway generally true for hospital wheelchairs. Graphs of E_α against α are drawn in Figure 2.

The relationship between α and handle height (normalised to an individual's shoulder height) has been found to be approximately linear (Fig. 3). This shows an example based on experimental data from 6 subjects pushing 1kg (best straight line to the data is drawn) and 4kg (data points also shown) horizontally against a fixed horizontal crossbar while walking on a treadmill at 1m/s. These pushing forces correspond to light and heavy pushing conditions for wheelchairs and represent respectively coefficients of rolling resistance corresponding to a best case of 0.02 and a very bad case of 0.1. These two graphs also illustrate the general case that, for a given handle height, the angle α decreases as the pushing force

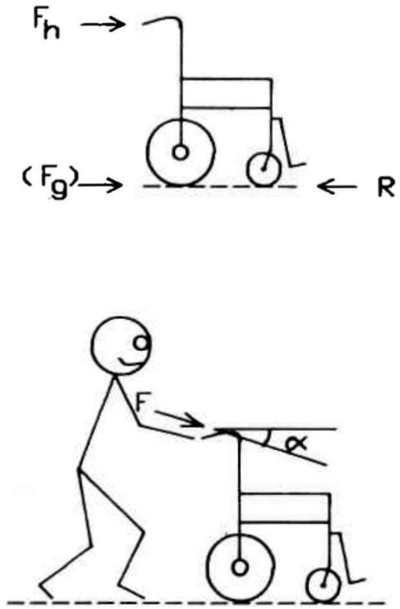

Fig. 1. Pushing forces.

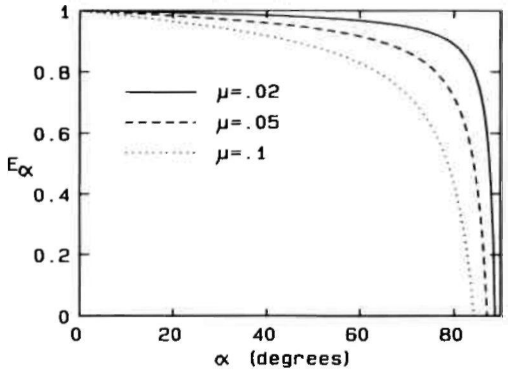

Fig. 2. Pushing Efficiency (Eα) versus Downwards Pushing Angle (α).

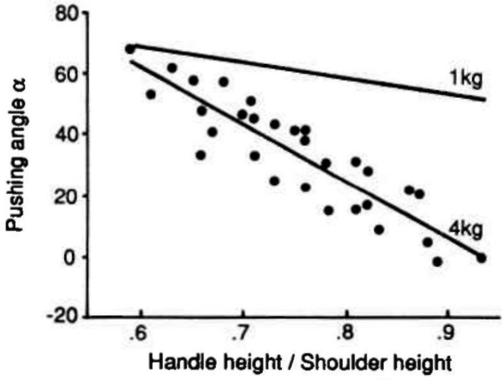

Fig. 3. Downwards Pushing Angle (α) versus Handle Height.

increases. This implies that a high rolling resistance gives rise to a low downwards pushing angle. The values for α from Figure 2 corresponding to the preferred handle heights of 0.73 to 0.74 of shoulder height when projected on to the graphs of Figure 3, give values of E_α of greater than 0.94 in the most unfavourable case. Designing wheelchairs with handles at the preferred height for attendants will not significantly affect the wheelchair's ease of propulsion.

Joint moments

The effect of handle height on the moments generated at the shoulder and the lumbosacral back joint in the sagittal plane has also been investigated for dynamic pushing, these joints being of interest because subjects during pushing tests noted discomfort in the shoulder area while pushing against a high handle, and because the lumbosacral area is particularly prone to injury from manual handling tasks (such as lifting). Figure 4 illustrates postural differences between pushing against a high and low handle. Interestingly, the magnitude of the moments at these joints has been found to be low at both high and low handle heights. The resultant pushing force vector passes close to the shoulder joint (S), producing a low turning moment, even taking the weight of the arms into account. The lumbosacral joint (LS) moments are also low in magnitude, the turning moment created by the pushing force being balanced to a large extent by that created in the opposite direction due to the weight of the trunk. This was generally found to be the case throughout the range of pushing forces, the pushing subjects adapting their postures to reduce shoulder and lumbosacral joint moments. A more extensive biomechanical analysis, including calculation of moments generated in the other reference planes, would therefore need to be conducted in order to identify the important joint moments for correlating comfort or discomfort of pushing with the height of the pushing handles.

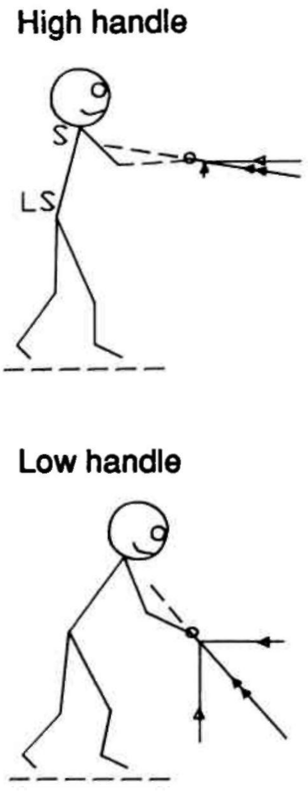

Fig. 4. Pushing posture.

Turning a wheelchair

The turning resistance of a wheelchair may be defined as the torque, or turning moment, required to turn the wheelchair in its smallest circle, which for a typical wheelchair with two castors and two fixed wheels has a centre halfway between the two fixed wheels. The magnitude of the torque is influenced by the castor trail of the wheelchair's castors, the friction generated between the fixed wheels and the ground as the wheels slide over it, and the positioning of the castors with respect to the centre of rotation of the wheelchair. The magnitude of the turning force which the attendant must exert is equal to the value of this torque divided by the distance from the centre of rotation of the chair to the operating handles. Since the handles of attendant propelled wheelchairs are always at the rear of the vehicle, chairs with rear castors will require less handle force for the same turning torque than those with front castors since the distance from the handles to the centre of rotation of the wheelchair is greater. There have been no specific biomechanical studies on the process of turning and manoeuvring attendant propelled wheelchairs. It would be difficult to design experiments which would cover the wide variety of manoeuvres which are made.

Subjective studies on the preferred location of castor wheels have however been undertaken, the conclusions of which will be presented in the next section.

Design features of attendant propelled wheelchairs

The occupants of attendant propelled wheelchairs are affected directly by the comfort offered in terms of seating, posture, ride comfort and various chair dimensions. The attendants, however, are confronted with the problems of transferring patients to and from the chairs and with the difficulty of pushing and manoeuvring the chairs. It is these two aspects, transfer and mobility, and the design features of wheelchairs that relate to them that are considered here. Research into attendant propelled wheelchairs carried out over several years in the School of Biomedical Engineering in Dundee University provides some of the background for the following discussion.

Patient transfer

The main components of the wheelchair which determine the ease of patient transfer are the footrests, armrests and brakes. These are considered in turn in the following.

Footrests

Footrests are essential on wheelchairs but they add considerably to the difficulty of transferring patients into or out of them. The process of removing the footrests from under the feet of a patient prior to transfer out of the chair (or the reverse procedure following transfer into the chair) carries risks of injury to the patient and risks to the attendant of strain, particularly to the back.

Some hospital wheelchairs have fixed footrests. These cause difficulties because patients either have to stand up on the footrest and then step down onto the floor from it, or they have to place their feet on the floor ahead of the footrest which makes standing up difficult because there is a large horizontal distance between the seat and the patients' feet. In the first case patients could fall while in the second case patients may have insufficient leg length to reach the floor and, even if they have, a very large lifting force is required from the attendant to get them standing vertically. The remaining hospital chairs and the domestic chair supplied by the National Health Service in the United Kingdom require the patients feet to be lifted and the footrests to be swung or slid away before placing their feet on the ground and helping them to stand. It is not uncommon for the patient's condition to be such as to make this procedure very difficult to carry out; attendants often have to kneel on the floor to accomplish it successfully.

Research in Dundee has been aimed at gaining a better insight into the footrest problem and producing improved designs (Frank and Abel, 1990). In an initial study, several different footrests, including some novel designs, were assessed by nursing staff in a variety of hospital wards. It was found that an elevating type of footrest was highly favoured above others. This footrest consisted of a single thin plate that could be lowered to, or raised from, the floor by means of a foot-lever operated by the attendant. In one of the wards (neurological) it was observed that nurses tending certain patients had severe difficulty with any of the footrests except the elevating type. The most immobile patients required two nurses to kneel on the floor in order to swing the patients legs forward and move the footrests into place.

Following this investigation into footrests on ward chairs, a similar study using porters' chairs was carried out. The elevating footrest was as favourable amongst porters as it had been with nurses. As a result of these studies a prototype wheelchair was constructed with an elevating footrest as the starting point of the design. A latching strut was utilized to hold the footrest in the raised position and the attendant was able to control the lowering as well as the lifting of the footrest.

In this particular design the front end of the chair, to which the footrest is attached, is raised using the front wheels as a fulcrum (Fig. 5). Other, perhaps more complex and costly, mechanisms could be used. For example, the footrest alone could move using a vertical slide or four-bar-link mechanism, or the chair and attached footrest could recline about an axis under the seat. A different approach to the footrest problem could be to retain the present type of footrest that folds or slides out of the way and devise a means for raising the patient's legs together or in turn. For example, the seat and back of the chair could recline so lifting the patient's feet clear of the footrests.

Armrests

The armrests of attendant propelled wheelchairs have to meet two main requirements where transfer is concerned: they should be correctly positioned to allow patients with good arm strength to assist themselves in rising, and they should be removable to allow the more disabled patients to be assisted or lifted from the chair. The prototype wheelchair produced in Dundee was constructed with armrests that protruded well forward, to give good support for the patient's hands when rising and which coud be folded down at the side of the chair to allow side transfers and good access when a patient needed to be lifted from the chair (Fig. 6). All the nurses and porters who assessed the prototype chair commented favourably on these armrests. A further advantage is the ability to fold away the armrests rather than having to remove them, which would leave the attendant holding the armrest and possibly having to leave it separately from the chair with the risk of it becoming lost.

Brakes

It is very important for a wheelchair to remain stationary and stable during patient transfer, particularly when patients transfer themselves or assist the attendant by utilising the armrests. Attendant propelled wheelchairs in hospitals generally have castored wheels at the rear of the chair (because fixed front wheels permit the use of a larger footplate) incorporating brakes which rotate with them. It is often the case that the chair will have been stopped with the castors in a position that makes the brakes awkward to apply. Another problem encountered with this type of brake is that it can become ineffective when wear has taken place. The brakes on the domestic attendant propelled chair supplied by the National Health Service in Britain act on the tyres and are applied by levers low down on the sides of the chairs. These brakes become ineffective when the tyres are below the proper pressure, a frequent occurrence (Abel et al., 1988). Also they are not easily accessed by the attendant.

Making the brakes reliable and easy to use increases the safety of a wheelchair when it is parked with an occupant present and during transfer operations. The work in Dundee produced an improved braking system for hospital wheelchairs (Fig. 7) in which the brakes on both rear wheels were applied simultaneously by a single foot-lever that was accessible from the rear and the sides of the chair. Because the brake was applied to the tyre by a rod passing down the centre of the castor

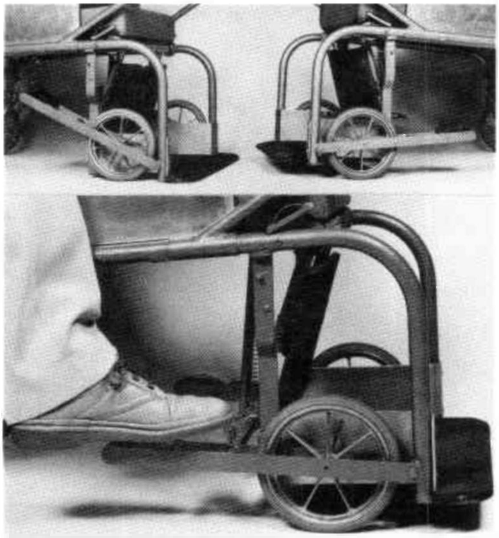

Fig. 5. Footrest design. Top, in raised and lowered position: Bottom, operation of mechanism.

Fig. 6. View of chair showing folded armrests and improved design of pushing handle.

pin, it could be applied with the castor in any position. In addition, a relatively long spring was used to hold the brakes on, with the result that very little reduction of brake effectiveness occurred when wear of the tyre and brake parts had taken place.

A secondary but very valuable aspect of the elevating footrest described above is that because the patient stands on the footrest, thus pressing it onto the ground, the chair is automatically well braked and completely stable during transfer operations. If nurses and porters were required to lower such a footrest whenever a chair was parked or a patient transferred, a normal brake for the chair could perhaps be dispensed with.

Mobility

The ease of pushing and manoeuvring, the difficulties that obstacles such as carpet edges and lift entrances cause, and the position of the pushing handles are all important aspects of chairs used for transporting patients.

The ease of pushing in a straight line on any given surface depends on the rolling resistance of the wheels and is particularly important where long distances may be travelled. Generally, rolling resistance decreases with wheel diameter and increased tyre hardness. Pneumatic tyres, however, have a lower rolling resistance than tyres of equivalent size made from soft rubber or polyurethane (Frank and Abel, 1989). There is a negligible contribution to rolling resistance from ball or roller wheel bearings whereas journal bearings may add to it by up to 50% (Frank and Abel, 1989). Pneumatic tyres would be inconvenient and unnecessary on hospital chairs but the combination of light weight, good shock absorption and low rolling resistance makes them more attractive for the folding type outdoor chair. The reason for not using cheap small wheels with hard tyres on hospital chairs is that both these factors make the chair very much more prone to being impeded or stopped by small steps such as carpet edges or the misaligned levels that often occur at the entrance to lifts (Frank and Abel, 1989).

Castor trail (the horizontal distance between the wheel axis and the axis of the castor bearing) is significant in that the greater it is made the less prone the castor will be to shimmy (rotational vibration) and the easier it will be to turn the wheelchair when starting from rest. Work carried out at the University of Virginia (Kauzlarich et al., 1984) has shown that wheels with a low moment of inertia about a diameter (i.e. lighter wheels) are also less prone to shimmy.

Chair manoeuvrability depends on several factors and is obviously important in hospital ward areas. Studies of manoeuvrability have been carried out in Dundee by using test

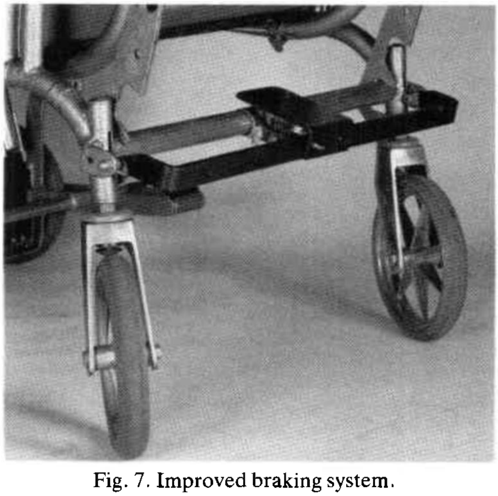

Fig. 7. Improved braking system.

Fig. 8. A chair with wheels just behind the centre of gravity.

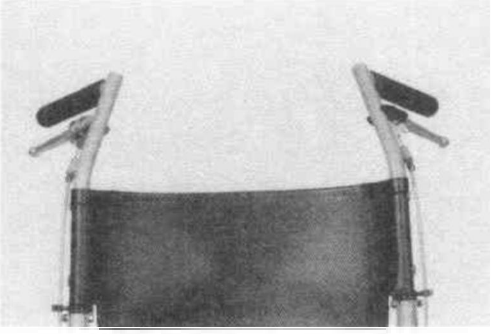

Fig. 9. Handle position on domestic chair.

circuits and mazes and by measuring wheelchair turning forces. The mazes consisted of routes along which the volunteers pushed a variety of occupied wheelchairs. The number of bumps, stops and reverses were counted and the volunteers were asked to give subjective comments. The results indicated that the most manoeuvrable chair is one where the fixed wheels are as near to the centre of gravity as possible. This also reduces turning forces to a minimum. An example of a chair constructed with the fixed wheels just behind the centre of gravity is shown in Figure 8. It can be seen that a pair of small rear wheels, which are not touching the ground, have been added to prevent the chair tipping over backwards. The study showed that front castors generally give better manoeuvrability than rear castors. However, subsequent studies in hospitals did not confirm the desirability of front castors. Porters, especially, preferred rear castors, probably due to the fact that chairs have to be pulled, rather than pushed, through the numerous swinging doors (fire doors, ward entrances etc.) that are found in hospitals.

The positions of the pushing handles currently used on attendant propelled wheelchairs are determined by mechanical convenience rather than ergonomic principles; they are either in the form of a horizontal cross-bar at the rear of the chair or a pair of backward pointing handles extending from the chair back. The results of the pushing studies described earlier suggest that current handles are too low and incorrectly angled for comfort. A handle designed for hospital wheelchairs using the results of the pushing studies can be seen in Figure 6. User trials of this handle indicated that not only is it comfortable when pushing but also it allows single handed pushing or pulling (because the handle can be held centrally) and it makes the chair easy to turn when the attendant approaches the chair from the side. A similar handle position could also be achieved on the domestic chair as demonstrated by the example show in Figure 9.

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Pushchairs

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Abstract

Pushchairs for adults are used by two distinct groups: the high dependency users who cannot walk or use a self-propelling chair and the occasional users who may be able to walk indoors but are unable to walk significant distances outdoors. In the past, both disparate groups were provided with similiar wheelchairs described as Model 9 or Model 10 in the United Kingdom. For the high dependency user the wheelchair may be individually adapted to accept specialized supportive seating and pressure relief cushions. The standard wheelchair without adaptation is supplied to the occasional user.

For disabled children, the UK wheelchair service provides about 1200 pushchairs and buggies. About 400 of those are the more specialized type such as the Avon, while the rest are standard children's buggies, openly available at a High Street shop. The continued free supply of the standard buggy through the UK Wheelchair Service is questionable.

A recent survey carried out by the UK Wheelchair Service showed that prescribers were not aware of the importance of lightness. foldability and appearance to parents and carers and conversely that parents often did not understand the necessity for supportive seating.

The prevention of deformities in children by providing correctly supportive wheelchair seating is accepted. The Disablement Services Authority in the UK is investigating the possibilities of producing children's wheelchairs that will satisfy the requirements of user, parent and prescriber.

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Introduction

Pushchairs have very different connotations for adults and children. In general, when prescribed for an adult a pushchair symbolises another unfortunate milestone in the progress of a chronic medical condition. Children however, are transported in "normal" buggies until they master the skills of ambulation. Those who never learn to walk look upon buggies initially and wheelchairs later as a means of reducing their handicap. Many in this group of children may use a self-propelling wheelchair or an electric wheelchair whilst only the most severely disabled rely entirely on a pushchair. Prescribers of wheelchairs must be aware of these different perceptions and not only prescribe the correct hardware but also introduce the pushchair at the most propitious stage in the course of the medical condition.

Adult pushchairs

Adult pushchairs are indicated for two quite different groups: the high dependency user and the occasional user.

The high dependency user

This user group being unable to walk is dependent on a wheelchair at all times. While able to use a powered wheelchair indoors some require a pushchair for outdoors only, others more severly disabled use a pushchair all the time.

The commonest conditions that warrant a pushchair are:-

a) The progressive neurological conditions such as multiple sclerosis, Parkinsons disease and the severely damaged stroke patient.

b) The mentally handicapped with associated mobility problems.

c) The late stage musculoskeletal conditions such as rheumatoid arthritis.

This high dependency group uses their pushchair for between 40 and 100 hours per week. Just over 33% of all pushchair users come into this category (Internal DHSS Survey).

The occasional user group

This group is less disabled and most can walk very short distances. The wheelchair is required for outdoor excursions and the user does not have the strength or stamina to use a self-propelling wheelchair. It would be fair to say that many would derive great benefit from having an electric outdoor wheelchair, were they available.

The vast majority of occasional users are elderly but the group also includes those with limited mobility resulting from end stage cardio-respiratory disease, strokes and major joint arthropathies. The pathologically obese are increasingly included in this category.

Occasional users make up 67% of all pushchair users and in 1987 accounted for 32,000 prescriptions in England and Wales (Internal DHSS Survey).

It is a sad reflection of the inadequate research into the requirements of pushchair users that, in Britain identical models are prescribed to both the high dependency and occasional user. The range is small but the general purpose design has undergone considerable mutation so as to achieve a compromise that is fairly cost effective.

The original design specification stated that the pushchair should be comfortable for the occupant and also carer (pusher) friendly. It should be foldable, transportable in a modern car, and easily stored in today's compact house. Most manufacturers have opted for the traditional design of two side frames held together by cross braces. The seat and backrest are made of polyvinyl cotton fabric which is waterproof and flame retardant.

In the UK the commonest pushchairs are the Model 9 and the Model 10. The Model 9 (Fig. 1) with very minor variations, is manufactured by various companies. The Model 10 is manufactured by the Barrett Company (Fig. 2). Its major feature is its ability to be transported in the boot of a Mini car when folded (Fig. 3). In addition, the Model 10 has a lower seat to ground height and a somewhat easier tipping mode. In both models the sling seat may be improved by using a cushion with a rigid base, or, if desired, any other proprietary cushion may be used.

There are other less commonly used pushchairs. The Everest and Jennings or Carters

Fig. 1. The Model 9.

Fig. 2. The Model 10.

heavy duty wheelchair is indicated when the occupant weighs over 88 kg. The Newton lightweight has a scissor type of cross brace with detachable rear wheels. In practice, some find it difficult to operate.

A great deal of modification and adaptation is possible to any of these wheelchairs. Suffice to say that the customisation is only limited by the imagination of the prescriber and the available resources. The pushchair is often modified for use as the carriage of specialised seating systems such as by use of a moulded seat (Fig. 4). It is worth remembering that a self propelling wheelchair (with large rear wheels) makes a more efficient pushchair when the kerbs are deeper, the cobbles larger, and the terrain more difficult.

The Trends

The demand for pushchairs is increasing at a faster rate than can be explained by demographic trends alone. Population studies confirm that there will be an increase in the elderly population for the first 10 or 15 years of the next century. This will be reflected by a greater demand for pushchairs and Table 1 confirms a much greater uptake after the age of 80 years (Internal DHSS Survey). More importantly, the determination of the elderly disabled to become mobile, together with, a more accepting attitude of society at large to accomodate the wheelchair user, has heightened demand.

Table 1. Wheelchair uptake in the elderly population.

	1982	1985
Age 70 — 80 years	1:115	1:70
Age 80+ years	1:50	1:40

The McColl report (DHSS, 1986) recommended the introduction of a pushchair designed specifically for the elderly occasional user. The report estimated a large uptake and savings of £3 million to the Wheelchair Service. Manufacturers were invited to produce a low cost disposable wheelchair and so far 4 models have been evaluated. These new wheelchairs have not improved on the existing Models 9 and 10 and the expected savings have not been achieved.

Children's Pushchairs

The commonest indications for prescribing a child's pushchair are:-

a) Neurological conditions with associated musculoskeletal pathology as seen in Cerebal Palsy, Spina Bifida and Muscular Dystrophy.
b) Mental Handicap.
c) Long term immobilisation, for example the child in frog plasters while undergoing treatment for congenital dislocation of the hip.

The first group is the most demanding and requires accurate assessment, prescription and

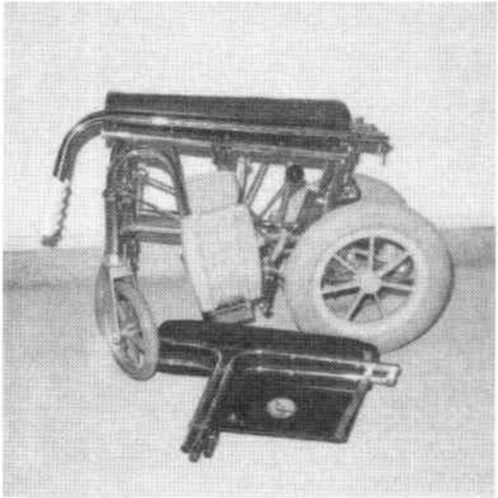

Fig. 3. The folded Model 10.

Fig. 4. Moulded seat in a pushchair.

follow up. It is often the case that the severity of the physical disability will not allow the child to exploit his or her mental abilities until satisfactory seating is achieved. It is also the case that these children are under the care and supervision of many professionals such as a Neurosurgeon, Orthopaedic Surgeon, Physiotherapist, Speech Therapist, etc, who may place contrasting requirements on the seating position. However, it is equally important to consider the views of the user, parent, carer and teacher with regard to comfort, communication, environment of use, transfers and transport, feeding, toileting and all the other tasks of daily living. There is no merit in prescribing a wheelchair system unless the user and carers are convinced of its benefits and the practicality of its use.

Most professionals agree that a firm yet padded seat and backrest together with options for head and thoracic supports are required. Users, parents and carers value lightness, foldability, transportability, modern cosmesis and a simple easy to use harness. Most want a "comfortable" position for the child which in effect implies an upright position when static and a more reclined position for transportation, feeding or taking a nap. A satisfactory children's pushchair must attempt to balance these sometimes conflicting aspirations, and reach a sensible compromise.

The wheelchair service in the UK currently provides about 12,000 children's vehicles a year. About 500 of these are the more specialised models such as the Avon and the Thames Tilt and Relax, while the remaining 11,500 are simple buggies which are readily available at most high street stores.

The Avon (Fig. 5) was designed and is manufactured by the Newton Company (a subsidiary of the Spastics Society). It has a padded wooden frame providing a 90 degree seat/backrest angle. The entire seat may be reclined and a wide range of support pads is available. It is unfortunately a large cumbersome vehicle, best suited for purpose built institutions and extremely awkward in the average British house. Furthermore, its inability to fold makes tranportation in a family car very difficult. The Thames Tilt and Relax is of similar design.

The standard buggies supplied are the Cindico and McLaren range though some other brands may also be available. For the larger child the McLaren Major Buggy (Fig. 6) will carry a load up to 40 kg. The lightness and compactness of these folding buggies is self evident but there are adverse long term effects of the sling seat on the posture and seating position.

Recently a wider range of children's buggies has been introduced onto the market. These have a well upholstered seat with firm base and backrest. They have more modern design profile and a robust construction that permits a high degree of outdoor activity. The Sulky and

Fig. 5. The Avon

Fig. 6. The McLaren Major Buggy

Fig. 7. the Alvema

the Alvema range (Fig. 7) are good examples. They are all heavier than might be desired and may be awkward to fold. Unfortunately, their exorbitant cost will restrict their routine issue through the Wheelchair Service.

It remains a challenge to the Wheelchair Manufacturers to design a correctly supportive, adjustable child's pushchair that meets the requirements of the user while remaining cosmetically attractive and affordably priced. There are encouraging signs that this challenge is now being taken seriously by some UK manufacturers.

(This article represents the authors personal views which are not necessarily the views of the Disablement Services Authority.)

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Wheelchair occupant restraints in motor vehicles

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Abstract
The issue of safety for wheelchair users in motor vehicles has been raised in Australia by parents of young people with disabilities. Investigations revealed that wheelchair users were not covered by any legislated safety requirements, and each case received special dispensation from compliance with regulations covering the able-bodied population. Dynamic testing of restraint systems at the University of Michigan had revealed that existing systems were unsafe. Dynamic tests confirmed those findings on systems used at that time in Australia.

Testing led to the design, development and marketing of a new wheelchair occupant and restraint system which remains a system of choice for use by organisations where the same people use the same buses in the same position each day. Australian Standard 2942-1987, Wheelchair Occupant Restraint Assemblies for Use in Motor Vehicles, has since been developed. It establishes design and performance requirements for these restraints and includes details of dynamic testing procedures.

This paper describes the development of the above restraint system and the subsequent Australian Standard.

Background
The issue of safety for wheelchair users in motor vehicles was brought to the author's attention in 1981 by parents of children and adolescents attending his centre. Initial investigations revealed that wheelchair users were not covered by any legislative safety requirements, and each case received special dispensation from compliance with regulations covering the able-bodied population.

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An extensive programme of dynamic testing of restraint systems at the University of Michigan had demonstrated that restraints in use at that time in the U.S. were not crashworthy (Schneider et al., 1979; Schneider, 1981[1 and 2]).

Research at several centres identified specific crashworthiness design principles for transporting people with disabilities in buses:

1. Wheelchairs should not be placed in a side facing orientation because the wheelchair user is particularly vulnerable to injury during a common frontal collision (Schneider et al., 1979; Schneider, 1981[1 and 2]).
2. Wheelchair securement hardware must be of adequate strength to withstand forces in the order of 25 times the combined weight of the wheelchair and occupant for a very brief time (approximately 100 ms) during a collision. Results of testing indicated that the primary weakness in most securement systems was not the wheelchair but the securement hardware (Schneider et al., 1979; Schneider, 1981[1 and 2]).
3. The wheelchair and its occupant should be secured independently; a single lap belt anchored to the floor or wall should not be used to secure both the wheelchair and the occupant, because in the event of an accident, unduly high loads would be placed on the occupant (Schneider, 1981[1 and 2]). Loads should be applied to the pelvis and other skeletal structures of the body (Schneider et al., 1979).
4. The restraint system must be anchored to the metal frame of the vehicle, not to unsound metal, or to wood or plastic structures. Wheelchair attachments should be at tubing joints such as the seat frame/rear upright junction and not at the centres of wheelchair tubing (Schneider, 1981[2]).
5. An upper torso restraint is an advantage in preventing the head from hitting vehicle

structures. A broad padded head restraint can prevent backward head excursion that can result in a whiplash neck injury (Schneider, 1981[2]; Kallieris et al., 1981).
6. The occupant support surface, often a vinyl seat, must be in good condition.
7. Strapping one side of a forward facing wheelchair to the side of the bus is unlikely to achieve complete restraint even in a direct frontal impact (Schneider, 1981[1]).

A survey of restraint systems in use at the author's centre at that time (Seeger and Caudrey, 1983) concluded that:
1. Some restraints needed to be strengthened.
2. The incidence of side facing bus seats and wheelchairs should be reduced. (Side facing bus seats and wheelchairs have since been eliminated in Australia.)
3. Much greater use needed to be made of head restraints. In a few cases lap belts were absent and were subsequently fitted.

Dynamic testing

Dynamic tests of restraint systems in local use were necessary to demonstrate the problems to management, transport officers and users. The technique of tying wheelchairs to side bars in the bus, which was in widespread use in Australia, had not been tested in any of the US tests.

Fortunately access was available to a test sled owned by a seatbelt manufacturer. In tests, all the restraints in local use were shown to be ineffective, even in moderate collisions. Another common method of fastening wheelchairs in motor vehicles was also tested; a floor pod, stem, and clamp which fastened to the wheelchair frame. It was ineffective even in a moderate collision and, in any case, was only a wheelchair restraint, not a wheelchair occupant restraint. Dynamic tests confirmed that systems used at that time in Australia were not crashworthy (Seeger, 1983).

Development of a wheelchair and occupant restraint system

A new concept was developed using standard seatbelt metal fasteners and 50mm seatbelt webbing to restrain both the wheelchair and the occupant (Seeger and Luxton, 1984). It consisted of:
- webbing floor mountings at the front uprights
- webbing floor mountings at the rear uprights
- brackets which U-bolt to the rear uprights of the wheelchair immediately below seat level (Fig. 1). When the wheelchair is not restrained in the vehicle, the left side buckle mates with the right tongue. The brackets also secure the two halves of the occupant's lap belt.

Because of the structural weakness of wheelchairs, it was recognised as unlikely that wheelchair occupants would ever be quite as safe in motor vehicles as able-bodied people in car seats. Dynamic test conditions of full adult restraints in cars were considered too difficult to attain in wheelchair occupant restraints. The system was tested therefore to dynamic test conditions based on Australian Standard 1754, Child Restraints for Passenger Car Derivatives, except that a 74 kg (50th percentile) adult male dummy was used. The system successfully restrained chair and occupant in front, side and rear impacts. An accessory webbing chest strap around the dummy and the wheelchair uprights was used in the side and rear facing tests.

The advantages of this restraint system are:

1. It is simple, unobtrustive and suitable for buses and small vehicles.
2. It is applicable to the majority of existing wheelchairs without significant modifications.
3. It is manufactured from automotive quality materials which are subject to automotive quality control procedures.
4. It is easy to install and it is recommended that relevant State Traffic Authorities check to ensure a safe installation.
5. It is easy to use since all mating parts are seatbelt tongues and buckles.

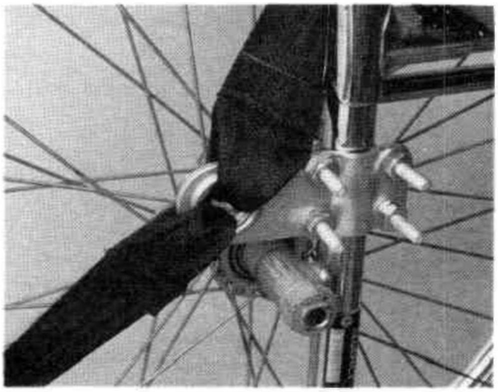

Fig. 1. Safe-N-Sound wheelchair and occupant restraint systems attached to rear upright of wheelchair.

6. It is commercially available from Safe-N-Sound for only $A77 (1989 price) plus installation.

The disadvantages of the new restraint system are that brackets must be attached to each wheelchair using the system and there is no upper torso restraint or head restraint, although both may be fitted separately.

This wheelchair occupant restraint system remains the system of choice for use by organisations where the same people use the same buses in the same position each day.

Australian Standard 2942-1987

The Australian Standard 2942, "Wheelchair Occupant Restraint Assemblies for Use in Motor Vehicles" (Australian Standard 2942-1987; Fisher et al., 1987), was subsequently developed. The need for a Standard became very apparent, so that providers of transport for people in wheelchairs could determine if their restraint systems were crashworthy, and manufacturers could have some clear design guidelines for future restraint systems. Australian Standard 2942 has served both of these functions admirably. It establishes design and performance requirements for restraints and includes details of dynamic test conditions, clear zones around wheelchairs and occupants, and anchorage locations.

Under the Standard, a lap belt its the basic occupant restraint required, with the wheelchair restrained independently of the occupant. The Standard, instead of specifying a "standard" design for wheelchair occupant restraint assemblies, is intended to ensure effective crash protection for wheelchair occupants with a minimum of restriction on the design of the restraints. It requires that instructions for installation and use of restraints be provided. Also included in the Standard is an advisory section providing general information for restraint users, such as the types of wheelchairs best suited for use in vehicles. Australian Standard 2942 appears to be the first national Standard for wheelchair occupant restraint assemblies for motor vehicles. It has provided manufacturers with clear performance requirements and they have used it to design new systems (see Suppliers).

Further information

An informative brochure and a video titled "Wheels on Wheels" were also produced and are available from the author at Regency Park Centre.

International Standard

An International Standard is now being drafted, based on Australian Standard 2942. Several important issues are still to be agreed on. Among them are:

- Englargement of the standard to cover public transport, vehicle drivers and wheelchair hardware.
- Agreement on appropriate dynamic test conditions.
- Concern over the strength of wheelchair frames.
- The degree of protection offered to a person in a wheelchair in comparison to passengers in car seats.
- How best to specify allowable excursion space so that each occupant is enveloped in a safety zone.
- Possible interaction with accessory systems such as impact absorbing bumpers.
- The use of a standard test seat or wheelchairs for dynamic testing of restraint systems.
- Specification of appropriate anchorages in the vehicle.

For further information contact the author.

Suppliers

(a) Safe-N-Sound P/L
99 Derby Road
SUNSHINE VIC 3020
Australia
Tel: (03) 311 0611
Fax: (03) 311 5798

(b) Easy Transs
Distributor: Alexander Packaging P/L
1 Brisbane Street
ELPHIN VIC 3095
Australia
Tel: (03) 465 7411

(c) Mobil Tech Four Point
Distributor: Maverick Motor Industries
6 Williams Avenue
EAST KEILOR VIC 3033
Australia
Tel: (03) 336 4522
Fax: (03) 336 1930

(d) Special Purpose Vehicles P/L
31-33 Parramatta Road
LIDCOMBE NSW 2141
Australia
Tel: (02) 648 3477
Fax: (02) 648 3467

REFERENCES

Australian Standard 2942–1987. Wheelchair Occupant Restraint Assemblies for Motor Vehicles – Sydney: Standards Australia, Sydney, 1987.

Fisher W. E., Seeger B. R., Svensson N. L. (1987). Development of an Australian Standard for wheelchair occupant restraint assemblies for motor vehicles. *J. Rehabil. Res. Dev.* **24(3)**, 23–34.

Kallieris D. *et al.* (1981). Behaviour and response of wheelchair, passenger and restraint systems used in buses during impact. Proceedings of the 25th Stapp Car Crash Conference. San Francisco: Society of Automotive Engineers, Inc., 613–647.

Schneider L. W. (1981[1]). Dynamic Testing of Restraint Systems and Tie Downs for use with Vehicle Occupants Seated in Powered Wheelchairs. University of Michigan Highway Safety Research Institute, 1981.

Schneider L. W. (1981[2]). Protection for the severely disabled – a new challenge in occupant restraint. The Human Collision; Proceedings of an International Symposium on Occupant Restraint, June 1–3, 1981, Toronto, Ontario, Canada. Edited by R. N. Green, E. Petrocelli. Martin Grave ILL: Association of Automotive Medicine.

Schneider L. W., Melvin J. W., Cooney C. E. (1979). Impact sled test evaluation of restraint systems used in transportation of handicapped children. Technical Paper 790074. Society of Automotive Engineers, Inc., 1979.

Seeger B. R., Caudrey D. J. (1983). Crashworthiness of restraints for physically disabled children in buses. *Rehabil. Lit.* **44**, 332–355.

Seeger B. R. (1983). Crashworthy restraints for wheelchair occupants in motor vehicles. *Tech. Aid Disabled J.* **3(4)**, 35–41.

Seeger B. R., Luxton R. E. (1984). A crashworthy restraint system for disabled people in wheelchairs in motor vehicles; Proceedings of the 2nd International Conference on Rehabilitation Engineering, Ottawa, 17–22 June, 1984. – Bethesda MD: Resna, pp 17–18.

International Newsletter
Spring 1991

Swedish National Member Society regrets that it has had to cancel the scientific seminar on Clinical Biomechanics of the Foot and Shoe, June 10–13, 1991 at Jonkoping.

United Kingdom National Member Society in collaboration with the **Netherlands National Member Society** will hold its Annual Scientific Meeting April 10–12 at the University of East Anglia, in the historic city of Norwich. The conference will include scientific papers and a full commercial exhibit as well as scientific exhibits and poster displays. Professor Jan Cool of the Technical University of Delft will speak on "Externally Powered Prostheses and Orthoses." The conference will also include a forum on the single European market, anticipating removal of economic barriers in 1992. Mr. N. A. Jacobs, Mr. J. J. Shorter, and Mr. T. J. Welsh will discuss recognition of qualifications, commercial implications, and quality assurance standards. Papers are invited on prosthetics, orthotics, seating, wheelchairs, communication aids, and other rehabilitation engineering topics and rehabilitation. For details, contact Dr. D. J. Pratt, ISPO Norwich '91. Orthotic and Disability Research Centre, Derbyshire Royal Infirmary, London Road, Derby DE1 2QY, England. Telephone 0332–47141, extension 2870. Commercial enquiries should be directed to Mr. J. R. Ronald, Hugh Steeper Ltd, DSA, DSC, Sherwood Hospital, Hucknell Road, Nottingham, England. Telephone 0602–606048. Netherlands members should contact J. H. Arendzen, MD, Department of Rehabilitation, University Hospital, Oostersingel 59, 9713 EZ Groningen, Netherlands. Telephone 050 612295.

The Department of Orthopaedic and Trauma Surgery, University of Dundee, and Tayside Rehabilitation Engineering Services, Dundee Limb Fitting Centre, Tayside Health Board, in association with ISPO, the Association of Prosthetists and Orthotists, the Biological Engineering Society, and the British Orthopaedic Association will sponsor an International Conference on Orthotics in Dundee, Scotland, September 16–20, 1991. Under the leadership of David Condie, Secretary General, the conference will combine scientific meetings and exhibitions of scientific and commercial interest for the physicians, surgeons, orthotists, therapists, engineers, and others involved in the prescription, design and supply of orthoses. An extensive social programme is planned. The faculty will include experts from the United Kingdom, Switzerland, United States, Australia, Sweden, Yugoslavia, Malaysia, India, and Denmark. For details, contact The Secretariat, Dundee '91. Dundee Limb Fitting Centre, 133 Queen Street, Broughty Ferry, Dundee DD5 1AG, Scotland.

Korea National Member Society announces its current officers: Jung-Soon Shin, MD, professor of rehabilitation medicine is the Vice Chairman; Myung-Sang Moon, MD, professor of orthopaedic surgery is secretary, and Sae-Yoon Kang, MD, Professor of rehabilitation medicine is the treasurer. Chairman Yong-Pal Ahn, MD died recently.

United States National Member Society held its annual meeting in March in San Diego, California. The theme of the scientific programme was brachial plexus injuries. Newly elected members of the Board of Directors are Frank Gottschalk, MD, John Michael, CPO, and Terry Supan, CPO.

Joan E. Edelstein
Editor

The Brian Blatchford Prize

The Brian Blatchford Prize has been established by the Blatchford Family to honour the memory of Brian Blatchford. It is awarded every three years at the World Congress of the International Society for Prosthetics and Orthotics.

The next Prize will be awarded at the Seventh World Congress ISPO to be held in Chicago, USA from 28th June – 3rd July, 1992. On this occasion the Prize will be £2,200 and will be awarded for a recent outstanding innovation in prosthetics and/or orthotics practice. The innovation should be related to a piece of prosthetic and/or orthotic hardware, or a scientifically based new technique which results in a better prosthesis or orthosis. The innovation should have reached a sufficiently advanced stage to ensure that it can be used successfully on patients.

The applicant or nominator should initially present evidence detailing the innovation, together with a sample of the device if appropriate, and send it to reach the President of ISPO by 1st November 1991 at the following address:

Professor W. H. Eisma
Elswout 2
9301 TS Roden
The Netherlands

The innovation shall be presented at the Seventh World Congress and duly published in Prosthetics and Orthotics International.

The President and Executive Board of the International Society for Prosthetics and Orthotics and the Blatchford family reserve the right to withhold the Prize should no suitable applicant be submitted.

The Forchheimer Prize

The Forchheimer Prize has been established by the Forchheimer family to honour the memory of Alfred Forchheimer. It is awarded every three years at the World Congress of the International Society for Prosthetics and Orthotics.

The next Prize will be awarded at the Seventh World Congress of ISPO to be held in Chicago, USA from 28th June - 3rd July, 1992 for the most outstanding paper on *Objective Clinical Assessment, Clinical Evaluation,* or *Clinical Measurement* published in Prosthetics and Orthotics International during the three years prior to the Congress.

The President and Executive Board of the International Society for Prosthetics and Orthotics and the Forchheimer family reserve the right to withhold the Prize should no suitable paper be published.

Calendar of Events

5–9 May, 1991
4th International Pre-Prosthetic Surgery Conference, Adelaide, Australia.
Information: Multinational Meetings Information Service BV, J. W. Brouwersplein 27, PO Box 5090, 1007 Amsterdam, Netherlands.

8–12 May, 1991
Orthopaedic and Rehabilitation Technology Trade Fair and Congress, Berlin, Germany.
Information: AMK Berlin Ausstellungs-Messe-Kongress-GmbH, Messedamm 22, D-1000 Berlin 19, Germany.

26–29 May, 1991
5th Canadian Congress of Rehabilitation, Prince Edward Island, Canada.
Information: Congress Secretariat, CRCD, 45 Sheppard Ave. E., Suite 801, Toronto, Ontario M2N 5W9, Canada.

3–6 June, 1991
American Orthopaedic Association Annual Meeting, Palm Beach, USA.
Information: AOA, 222 S. Prospect Ave., Park Ridge, IL 60068, USA.

6–8 June, 1991
9th Annual Future Show, San Francisco, USA.
Information: Marjorie D. Price, 1130 Hightower Trail, Atlanta, GA 30350, USA.

16–19 June, 1991
ASME Applied Mechanics and Biomechanics Conference, Colombus, Ohio, USA.
Information: Dr. R. L. Spiker, Dept. of Mechanical Engineering, Rensselaer Polytechnic Institute, Troy, NY 12180, USA

21–26 June, 1991
14th Annual RESNA Conference, Kansas City, USA.
Information: Susan Leone, RESNA, 1101 Connecticut Ave. NW, Suite 700, Washington DC 20036, USA

23–27 June, 1991
Annual Conference of the American Physical Therapy Association, Boston, USA.
Information: Information Dept:, APTA, 1111 N. Fairfax St., Alexandria, VA 22314, USA

24–26 June, 1991
7th Annual Meeting of the International Society of Technology Assessment in Health Care, Helsinki, Finland.
Information: ISTAHC–91, Congress Management Systems, PO Box 151, 00141 Helsinki, Finland.

7–12 July, 1991
16th International Conference on Medical and Biological Engineering, Kyoto, Japan.
Information: Dr. O. Z. Roy, IFMBE, c/o National Research Council of Canada, Room 164, Bldg. M50, Ottawa, Ontario, K1A 0R8, Canada.

28–31 July, 1991
International Symposium on 3D Analysis of Human Movement, Montreal, Canada.
Information: 3D Analysis Symposium, Lab. d'Etude du Mouvement, Centre de Recherce Pediatrique, Hopital Saint–Justine, 3175 Cote Ste–Catherine, Montreal, Quebec H3T 1C5, Canada.

28 July–2 August, 1991
11th Congress of the World Confederation for Physical Therapy, London, England.
Information: Secretariat, WCPT, Conference Associates, 27A Medway St., London SW1P 2BD, England.

5–7 August, 1991
4th European Congress on Research in Rehabilitation, Ljubljana, Yugoslavia.
Information: Crt Marincek, University Rehabilitation Institute, Linhartova 51, 61000 Ljubljana, Yugoslavia.

7–11 August, 1991
Southern Orthopaedic Association Meeting, Colorado Springs, USA.
Information: SOA, 222 S. Prospect Ave., Park Ridge, IL 60068, USA.

9–15 August, 1991
3rd International Abilympics, Hong Kong.
Information: D. Lynn Abels, 3rd International Abilympics Secretariat, 1st Floor, 57 Wyndham St., Central, Hong Kong.

27–29 August, 1991
2nd East European Conference on Biomedical Engineering and 3rd National Meeting of Czechoslovak Society for Biomedical Engineering, Prague, Czechoslovakia.
Information: J. E. Purkyne, BME Conference, PO Box 88, 120 26 Prague 2, Czechoslovakia.

5–7 September, 1991
3rd Meeting of the European Academy of Childhood Disability, Manchester, UK.
Information: Ms. O. Plunkett, MEIU, The Wolfson Centre, Mecklenburgh Square, London WC1N 2AP, UK.

6–8 September, 1991
2nd Scientific Meeting of the Scandinavian Medical Society of Paraplegia, Copenhagen, Denmark.
Information: Centre for Spinal Cord Injured, Rigshospitalet, TH2002, Blegdamsvej 9, DK–2100 Copenhagen, Denmark.

16–20 September, 1991
Dundee '91 — International Conference and Instructional Course on Orthotics, Dundee, Scotland.
Information: Dundee '91 Secretariat, c/o Dundee Limb Fitting Centre, 133 Queen St., Broughty Ferry, Dundee, Scotland.

17–19 September, 1991
4th International Symposium on Biomedical Engineering, Peniscola, Spain.
Information: 4th International Symposium on Biomedical Engineering, Universidad Politecnica de Valencia, PO Box 22012, 46071–Valencia, Spain.

24–26 September, 1991
Biological Engineering Society Annual Scientific Meeting, Birmingham, England.
Information: Mrs. B. Freeman, BES, RCS, 35 Lincoln's Fields, London W2 3RX, England.

27–28 September, 1991
Biomedical Engineering Society, Annual Fall Meeting, Charlottesville, USA.
Information: Biomedical Engineering Society, PO Box 2399, Culver City, CA 90231, USA.

1–6 October, 1991
American Orthotic and Prosthetic Association Annual National Assembly, California, USA.
Information: AOPA, 717 Pendleton St., Alexandria, VA 22314, USA.

13–16 October, 1991
7th International Conference on Mechanics in Medicine and Biology, Ljubljana, Yugoslavia.
Information: ICMMB 91, Technical Organiser, CANKARJEV DOM, Cultural and Congress Centre, Kidricev Park 1, 61000 Ljubljana, Yugoslavia.

20–24 October, 1991
Western Orthopaedic Association Meeting, Tucson, USA.
Information: H. J. Martin, 2975 Treat Blvd., D–4, Concord, CA 94518, USA.

21–23 October, 1991
Combined Meeting of the Orthopaedic Research Societies of USA, Japan and Canada, Alberta, Canada.
Information: Mrs. M. Aldridge, Conference Office, University of Calgary, 2500 University Drive N.W., Calgary, Alberta T2N 1NR, Canada.

23–27 October, 1991
Reha '91–Rehabilitation Aids for Handicapped Persons, Dusseldorf, Germany.
Information: Reha '91 Press Office, Eva Rugenstein, Messe Dusseldorf, Germany.

27 October–1 November, 1991
American Academy of Physical Medicine and Rehabilitation Meeting, Washington DC, USA.
Information: AAPM&R, 78 E. Adams St., Suite 1300, Chicago, IL 60603, USA.

31 October–3 November, 1991
13th Annual Meeting of IEEE Engineering in Medicine and Biology Society, Orlando, USA.
Information: Professor Joachim Nagel, Dept. of Biomedical Engineering, Research Centre, University of Miami, PO Box 248294, Coral Gables, FL 33124, USA.

3–8 December, 1991
Annual Meeting of the American Academy of Neurological and Orthopaedic Surgeons, Las Vegas, USA.
Information: American Academy of Neurological and Orthopaedic Surgeons, 2320 Rancho Dr., Suite 108, Las Vegas, NV 89102, USA.

5–6 December, 1991
3rd International Symposium on Computer Simulation in Biomechanics, Perth, Australia.
Information: Ms. R. Ingham, Dept. of Human Movement Studies, Univ. of Western Australia, Nedlands WA 6009, Australia.

9–13 December, 1991
13th International Conference on Biomechanics, Perth, Australia
Information: 13th ISB Congress Secretariat, Dept. of Human Movement Studies, Univ. of Western Australia, Nedlands WA 6009, Australia.

1992

19-24 January, 1992
ACOPPRA II, the 2nd International Conference of the Central American Association of Orthotists, Prosthetists, Rehabilitation Professionals and Affiliates, Panama City, Panama, Central America.
Information: Rita Chan de Lee, Secretary ACCOPRA, PO Box 26, Zona 1, Panama City, Republic of Panama.

31 January–2 February, 1992
International Congress and Workshop of the German Society of Orthopaedics and Traumatology on the Thumb and Wrist, Dusseldorf, West Germany.
Information: Dr. C. L. Jantea, Sec. Handsurgery and Rheumatology, Orthopaedic Dept. of the Heinrich Heine University, Moorenstr. 5, D–4000 Dusseldorf, Germany.

20–25 February, 1992
Annual Meeting of the American Academy of Orthopaedic Surgeons, Washington, USA.
Information: AAOS, 222 South Prospect, Park Ridge, IL 60068, USA.

7–12 April, 1992
American Academy of Orthotists and Prosthetists Annual Meeting and Scientific Symposium, Miami, USA.
Information: AAOP, 717 Pendleton St., Alexandria, VA 22314, USA.

8–10 April, 1992
ISPO (UK) Annual Scientific Meeting, Manchester, England.
Information: B. McHugh, NCTEPO, University of Strathclyde, Curran Building, 131 St. James' Rd., Glasgow G4 0LS, Scotland.

22–25 April, 1992
Independence '92 — International Congress and Exposition on Disability, Vancouver, Canada.
Information: Suite 2000, 1176 W. Georgia St., Vancouver, B.C., V6E 4A2, Canada.

28 June–3 July, 1992
7th World Congress of ISPO, Chicago, USA.
Information: 7th World Congress of ISPO, Moorevents, Inc., 400 North Michigan Avenue, Suite 2300, Chicago, IL 60611, USA.

14–18 September, 1992
XI World Congress of The International Federation of Physical Medicine and Rehabilitation, Dresden, Germany.
Information: Prof. Jurgen Kleditsch, Dept. of Physical Therapy and Research, Clinic of Orthopaedics, Medical Academy "Carl Gustav Carus" Dresden, Germany.

26–31 October, 1992
American Orthotic and Prosthetic Association Annual National Assembly, Orlando, USA.
Information: AOPA, 717 Pendleton St., Alexandria, VA 22314, USA.

ISPO Publications

V World Congress, July, 1986 Copenhagen
Programme and Abstracts $20 (US)

Standards for Lower Limb Prostheses
Report of a Conference, Philadelphia 1977 $20 (US)

The Deformed Foot and Orthopaedic Footwear
Report of the ISPO Workshop in Stockholm March 1977
Edited by B. Klasson
Co-Editors A. Forchheimer, J. Hughes, G. Murdoch ISPO Members $20 (US)
Non-Members $35 (US)

Directory of Films in Prosthetics and Orthotics
Compiled and Edited by J. E. Edelstein and R. G. Donovan
Published 1980 $15 (US)

Prosthetics and Orthotics International August 1983
Special Issue — Through-knee Amputation and Prosthetics
Edited by J. Steen Jensen $40 (US)

Prosthetics and Orthotics International April 1985
Special Issue — CAD/CAM Computer Aided Design and Manufacture
Edited by R. M. Davies
Photocopy of papers $40 (US)

Prosthetics and Orthotics in the Developing World with Respect to Training and Education and Clinical Services
Report of an ISPO Workshop Moshi, Tanzania
Edited by N. A. Jacobs, G. Murdoch
Published 1985 ISPO Members $15 (US)
Non-Members $25 (US)

Planning and Installation of Orthopaedic Workshops in Developing Countries
Edited by S. Heim (Co-ordinator), W. Kaphingst, N. A. Jacobs
Published 1986 ISPO Members $10 (US)
Non-Members $15 (US)

Training and Education in Prosthetics and Orthotics for Developing Countries
Report of an ISPO Workshop, Jönköping, Sweden
Edited by K. Öberg, G. Murdoch, N. A. Jacobs
Published 1987 ISPO Members $20 (US)
Non-Members $35 (US)

Up-Grading in Prosthetics and Orthotics for Technicians in Developing Countries Trained on Short Courses
Report of an ISPO Workshop, University of Strathclyde, Glasgow, Scotland
Edited by G. Murdoch, N. A. Jacobs
Published 1989 ISPO Members $20 (US)
Non-Members $35 (US)

Traumatic Amputations
Proceedings of an ISPO Seminar, Herzlia, Israel
Edited by H. Stein, T. Steinbach
Published 1989 ISPO Members $20 (US)
Non-Members $35 (US)

Above-Knee Fitting and Alignment
Report of ISPO Workshops held in Miami, Florida, USA and Chicago, Illinois, USA
Published 1989 ISPO Members $20 (US)
Non-Members $35 (US)

CAD CAM in Prosthetics and Orthotics
Report of an ISPO Workshop, Seattle, Washington, USA
Published 1990 ISPO Members $25 (US)
Non-Members $40 (US)

Prices include surface mailing.

Orders which must be accompanied by the appropriate remittance (cheque or international bank draft made payable to ISPO), should be sent to:

ISPO Publications
Borgervænget 5
2100 Copenhagen Ø
DENMARK

Prosthetics and Orthotics International, 1991, 15, 62–64

Seventh World Congress

28 June–3 July, 1992, Chicago, Illinois, USA

An Invitation

We, of the USA Member Society, cordially invite you to Chicago for the **Seventh World Congress of the International Society for Prosthetics and Orthotics** (ISPO). We are pleased that ISPO has selected North America for the Seventh World Congress and look forward to your attendance and participation.

The theme of the 1992 Congress is, **"Find the New World of Prosthetics and Orthotics Developing Around the Globe."** This theme acknowledges the past and the 500th anniversary of Columbus' voyage to the Americas, but more importantly it directs us to the future and to the new world of prosthetics and orthotics that people are developing around the globe. These people will be coming to Chicago to share their new knowledge, new developments, and new visions. We hope you will join them.

Chicago is a major medical centre of the USA, with strong traditions in rehabilitation and orthopaedics, and with well-known educational, clinical, and research programmes in prosthetics, orthotics, and rehabilitation engineering. Chicago is a vigorous and enjoyable city – a city of working people from all over the globe. We think you will enjoy the culture, beauty, diversity, and friendliness of this midwestern city by Lake Michigan. The Illini Indians called this place "Che-ca-gou" for the "wild onions" that grew along the river where it entered the lake. The first Europeans, Pere Jacques Marquette and Louis Joliet, arrived in 1673 and used Chicago as a portage at this continental divide of waterways. The city remains a transportation centre. It is accessible and waiting for you. Mark your calendars and plan a new voyage to find a new world of prosthetics and orthotics.

Dudley S. Childress, Ph.D.
General Secretary, Seventh World Congress

Maurice LeBlanc, M.E., C.P.
Chairman, US National Member Society of ISPO

Programme

The ISPO Seventh World Congress will consist of scientific, technical, clinical, and surgical papers; plenary sessions; instructional courses; scientific and commercial exhibits; poster sessions; a video and film programme; and technical tours. The Rehabilitation Institute of Chicago, near the site of the Congress, will host an "open house" where participants can also visit Northwestern University's Prosthetic-Orthotic Education Programme, the Prosthetics Research Laboratory, and the Rehabilitation Engineering Centre in Prosthetics and Orthotics.

A social programme and accompanying persons programme is planned so that you will find it easy to experience Chicago's outstanding architecture, parks, boat cruises, swimming and beaches. Plan to take part in the Independence Day celebration with a concert and fireworks on the evening of July 3 and with festivities on the 4th of July. Extend your stay with post-conference tours to the Grand Canyon, Canadian Rockies, or cities such as Washington, D.C.; San Francisco; or New Orleans. Chicago has direct flights to most points in North America.

Topics

Amputation & Surgical Procedures ⋆ Biomechanics: Modeling of Human Movement, Tissue ⋆ Consumer Viewpoints ⋆ CAD/CAM ⋆ Education ⋆ Footwear & Foot Problems ⋆ Management of Children ⋆ Orthotic Management of Fracture ⋆ Gait Analysis: Clinical, Research, Instrumentation ⋆ Historical & Cultural Issues ⋆ Locomotion Aids such as FES, Crutches, and others ⋆ Lower and Upper Limb Orthotics/Prosthetics ⋆ Materials ⋆ Patient Management ⋆ Recreation ⋆ Rehabilitation in Developing Areas ⋆ Seating, Positioning, & Wheelchairs ⋆ Spine Management & Spinal Orthotics ⋆ Testing & Standards ⋆ Physical/Occupational Therapy

General Information

Dates: 28 June–3 July, 1992

Location: Hyatt Regency Chicago Hotel
151 East Wacker Drive
Chicago, IL 60611 USA

Located in one of the USA's largest urban developments, the *Illinois Center*, the Hyatt is on the south bank of the Chicago River near the Michigan Avenue bridge. It is near the heart of the city, within easy walking distance of the Loop, North Michigan Avenue, Grant Park, and Lake Michigan; and close to many museums, shopping areas, restaurants, points of interest, and public transportation. The Hyatt Regency is accessible to persons with disabilities. High temperatures in Chicago during late June and early July average 28°C (83°F). However, the continental weather is highly variable and deviations of ±10°C (±18°F) from the norm are not uncommon.

Official Language: English.

Letter of Invitation: An official letter of invitation will be sent upon request. The invitation does not obligate the Organizing Committee to assume any financial burden for costs of attending the Congress.

Housing: A block of rooms has been reserved at the Hyatt Regency Chicago Hotel at attractive conference rates. Hotel reservation forms will be included with the Congress' Second Announcement.

Congress Airlines and Travel Bureau: American Airlines has been selected as the official airlines of the Seventh World Congress. Participating co-carriers include Midway Airlines, British Airlines, and Trans World Airways. Discount travel rates are available. Reservation information will be available with the Second Announcement.

Carlson Travel Network is the travel agency for the Congress and will be organizing post conference tours. Reservation information for these tours will be available with the Second Announcement.

For more travel information, call 1-(800) 331-8132 (outside Illinois, USA) or (312) 372-3313 (within Illinois, USA). This number is available from 8.30 to 17.00 hours Monday through Friday, USA Central Standard time.

Visa and Travel Regulations: Persons planning to attend the Congress from countries other than the USA should determine from the US Consulate in their country whether a visa is required in addition to a valid passport for US entry. If a visa is required, your Congress confirmation/receipt should be taken to the US Consulate office as evidence of your intention to attend the Congress. Immunizations are not required by the US Public Health Service.

Second Announcement: The second Congress Announcement, to be mailed in 1991, will include a pre-registration form, hotel reservation form, abstract/exhibit/presentation submission forms, travel information, and a preliminary programme for the Congress. To receive the second announcement and other Congress mailings, fill out the reply card, detach, and mail.

Reply Form

International Society for Prosthetics and Orthotics
VII World Congress
June 28 to July 3, 1992
Chicago, Illinois, USA

Please print

Name in Full (*Prof., Dr., Mr., Mrs., Ms.*) ____________

Title and Affiliation ____________

Mailing Address ____________

City ____________

State or Province ____________ Postal Code ____________

Country ____________

Telephone ____________

Fax ____________

Are you planning

To submit a Paper? Yes ____ No ____

To present Audiovisual material? Yes ____ No ____

A commercial Exhibit? Yes ____ No ____

A scientific Exhibit? Yes ____ No ____

To bring an accompanying person? Yes ____ No ____

Post-conference travel? Yes ____ No ____

Please list below any individuals whom you feel should be on our mailing list:

Congress Secretariat: Moorevents, Incorporated is acting as the Congress Secretariat. Should you have any questions or need additional information, please contact:

Moorevents, Inc.
400 North Michigan Avenue
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Chicago, IL 60611 USA
Phone (312) 644-5997
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