Dynamic arm supports

Overview and categorization of dynamic arm supports for people with decreased arm function

Loek A. van der Heide[1,2], Gert Jan Gelderblom[1], Luc P de Witte[1,2]

[1]Research Centre for Technology in Care
Zuyd University of applied sciences
Heerlen, The Netherlands
loek.vanderheide@zuyd.nl

[2]School for Public Health and Primary Care
(CAPHRI)
Maastricht University,
Maastricht, The Netherlands

Abstract—**In the 1940s the wish for independent feeding in polio survivors has led to the development of the first dynamic arm supports. By now polio is eradicated, but persons with difficulty to perform activities of daily living due to a limited arm function still exist. Many devices aiming to support these persons have been developed in the past 70 years. A review making an inventory of devices developed was performed in scientific literature databases, conference proceedings, assistive technology databases and by consultation of experts. A total of 97 devices were found, and three main categories were recognized: the non-actuated devices (N=39), the passively-actuated devices (N=24) and the actively-actuated devices (N=34). Of the 97 devices encountered 43 devices were commercially available in October 2012, the lowest percentage found in the actively-actuated devices. This means that the more advanced systems are not (yet) available for users. The continuous efforts in developing new devices suggest there is potential for actively activated arm supports. Developing these into products ready for the market would be a first step in fulfilling this potential.**

Keywords—dynamic arm supports, orthotics

I. INTRODUCTION

Dependence in eating of an increased number of polio-survivors in the 1940s has led to an increased need for support. In answer to this, feeders were developed, which were assistive devices supporting the lower arm, aiming to enhance the ability to eat. Although polio is eradicated, patients with neuromuscular diseases, such as Duchenne Muscular Dystrophy (DMD) experience similar dependence in Activities of Daily Living (ADL) due to decreased arm function. Improvements in care for DMD patients resulted in an increase in the life expectancy from 14,4 years in the 1960s to 25,3 years in the 1990s [1]. Despite these medical advances the increasing weakness in the upper extremity persists and as a consequence, the independence of DMD patients increases with increasing age [2]. Also Spinal Muscular Atrophy (SMA) is characterized by increased muscle weakness and atrophy, there is no remedy at the moment and care for these patients is mainly directed towards relieving the symptoms [3]. DMD and SMA are only two examples of diseases characterized by a decreased arm function.

The persistent need for assistive devices, has, since the polio-epidemic, resulted in the development of different devices supporting arm function in ADL. The devices developed in the past 70 years for this purpose have been referred to as dynamic arm supports or orthoses.

In the ISO 9999 classification [4], these devices are included as upper extremity orthoses and “forearm supports to permit manual operation”. Both categories contain a wide variety of devices. Static devices, such as splint, that do not permit joint motion, as well as dynamic devices that allow for motion of a joint are included in this classification. Performance of ADL tasks in general requires manual manipulation, implicating that the arm must transfer the hand to places where it can manipulate objects. Only for a limited set of tasks (i.e. typing) a static arm support will support task execution. Most ADL tasks require a mobile hand function for which reason the static devices are not thought to be able to contribute much during ADL performance. The focus of this article will therefore be on dynamic devices that facilitate arm function during the performance of ADL tasks solely. For the purpose of this article, these will be referred to as dynamic arm supports. In literature, these terms are used inconsistently, meaning that a name of a device does not always reflects its function.

Developments in the field of dynamic arm supports have been mostly influenced by technical developments. Technological advances offered the possibility to develop more complex devices. However, not all attempts to develop a dynamic arm support result in devices that are available commercially. To be used effectively by end-users, however, devices have to be available on the market. Several articles [5,6] refer to previous developments and indicate the devices that are commercially available. Although, it is unlikely this provides a comprehensive list of devices. In the light of the continuous developments in the field of dynamic arm supports, it is remarkable a review of devices have not been performed thus far. An overview could also help to distinguish the (lack of) more principle differences between the devices and will potentially decrease the existing confusion in terminology.

This study therefore reports on compiling and categorizing assistive devices that facilitate arm function in activities of

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daily living for people with decreased arm function. Secondly, it distinguishes between commercially available products and devices not being available on the market.

II. Methods

A. A systematic review of the literature

A systematic review of the literature was performed in Cinahl, Pubmed and the IEEE databases, using the following combination of MeSH terms or related terms and free text words: neuromuscular diseases, muscular dystrophies, muscular disease, muscle weakness, cerebrovascular disorders, multiple sclerosis, arm dysfunction, stroke, spinal cord injury, hemiparesis, arm, upper extremity, upper limb, forearm, robot*, arm support, exoskelet*, orthotic device and self-help device. Titles were scored for relevance independently by three reviewers on including reference to a device that assists in activity or movement of the upper extremity and to people with limited arm function. Titles were excluded if they referred to a) training or therapy, b) assisting hand function only or c) a static device. Articles not meeting the inclusion criteria obtained 0 points, meeting the criteria resulted in 2 points and when in doubt, the titles were given one point. When the sum of the scores equaled two or more the abstracts were subsequently assessed. Abstracts were assessed by two reviewers using the same in- and exclusion criteria. Abstracts of which the sum of the scores equaled two or more were assessed by their full text. The full texts were searched for mentioning of dynamic arm supports or references to such devices.

Besides the literature databases, a manual search was performed in Conference proceedings of the AAATE, RESNA, RESJA and ARATA and the pan European assistive technology database Eastin, Handywijzer (Dutch), AbleData and the Vilans Hulpmiddelenwijzer (Dutch). Google and GoogleScholar were searched using text strings. Experts consulted were manufacturers, distributors and an occupational therapist. Devices encountered in the aforementioned sources that probably were regarded as dynamic arm support were added to a database.

B. Creation of a Dynamic Arm Supports database

Every single device found was entered in a database and was further checked for being a dynamic arm support. A device was not regarded as a dynamic arm support when it a) was a static device (not permitting motion), b) was used for training purposes solely, c) was intended to be used therapeutically, d) supported hand function only (and not arm function), e) was used as a manipulator or f) applied Functional Electrical Stimulation (FES). Additional product information of the included devices was collected from articles, installation guides, catalogues and web pages of distributors and manufacturers. Of the devices recognized as dynamic arm support, commercial availability was determined. A device was regarded as commercially available if the device appeared on a website of a distributor or manufacturer in October 2012.

C. Categorization of Dynamic Arm Supports

A categorization was developed in which the devices were divided up on the basis of differentiating characteristics and functionalities. Categorization was regarded to be successfully completed when all devices without exceptions could be categorized. Working principles of devices commercially available and devices not available on the market were qualitatively compared for every separate category of devices.

III. Results

A total of 97 devices were regarded as dynamic arm supports, with developments originating from 1936 to 2011. The adopted categorization extend the categories identified previously by Rahman [7] and Cardoso [8]. To their two categories; passive devices (or non-powered) and active (or powered) devices we propose a further split up of the first group into two separate groups. The devices could be distributed completely over the following categories: non-actuated devices (N=39), passively-actuated devices (N=24) and actively-actuated devices (N=34) (table 1). The labels refer to technical characteristics and this distinction is then based upon the energy requirements to operate the device and the ability to store potential energy within the dynamic arm support. The three different groups will be described in more detail, along with examples of developed and commercially available devices and their working principles.

A. Non-actuated devices

Non-actuated dynamic arm supports are devices that do not require external energy for operation. A total of 39 non-actuated devices were encountered, of which 20 were commercially available and 19 were not commercially available in October 2012.

A common functioning principle encountered in these devices is the provision of low friction movement during horizontal motion. Commercially available examples to which this mechanism is applied are the Portable Zonco Arm support (ZoncoArm) and the Ergorest (Ergorest). This mechanical design can also be found in devices that are not commercially available such as the Alumium trough [9]. All three devices are intended to be used for keyboard operation or desk work. Provision of low friction movement can also be achieved by a suspending rope (without a counterweight). As can been seen for example in the commercially available Suspension Sling (JAECO Orthopedic) and the "separate overhead arm-suspension", developed by an orthopaedic centre, the Middlesex Hospital for one person specifically and which has never been available on the market [9].

Another functioning principle applied to non-actuated devices, is the see-saw mechanism that enables elbow flexion. Already in 1953, this mechanical principle was applied to the Balanced Forearm Orthosis and several other devices developed by the Georgia Warm Springs foundation, such as the corset-based feeder and the Barker feeder [10]. These devices are currently not commercially available, but were used in the past. The see-saw mechanism, however, is still applied to commercially available devices. Similar designs are found in devices, such as JAECO Orthopedic's "Standard Mobile Arm Support" (figure 1) and the TOP by Focal Meditech. A device in which movement of the leg against a movable board results in movement of the hand towards the face is the foot-operated feeder [10]. The Dynamic Triceps

Driven Orthosis can be fabricated by bioengineering shops or prosthetic laboratories from parts that are commercially available [11].

Figure 1. An example a non-actuated dynamic arm support (Standard Mobile Arm Support, JAECO Orthopedic)

B. *Passively-actuated devices*

Passively-actuated dynamic arm supports are devices that offer the ability to store potential energy within the device. 17 of the 24 encountered passively-actuated devices are commercially available. Some of these devices passively compensate for the effects of gravity achieved by a suspending rope using counterweights, such as the commercially available Sling (Focal Meditech) and the Mobility arm (Nitzbon, figure 2). Similar devices are found among the devices that are not commercially available, for example the Musgrave orthosis [12]. Compensation for the gravitational effects can also be achieved by means of springs or elastic bands used in combination with an arm trough. This can be found in devices such as the WREX (JAECO Orthopedic), the M.A.G. vertical orthosis (Proteor) and the TOP/Help (Focal Meditech), which are all commercially available. The assistive device for forearm lift [13] and the floating arm support [14] are similar, older, but not-commercially available devices.

Figure 2. An example of a passively-actuated dynamic arm support (Mobility arm, Nitzbon)

C. *Actively-actuated devices*

Actively-actuated devices require external energy for operation. In total, 34 devices were found and 6 of these are currently commercially available. The devices that are available on the market can work as an arm-lift, in most cases, operation of a switch results in depression or elevation of the lower arm. These devices are the Top/Help Electric (Focal Meditech) and the Neater Arm Support (Neater Eater). The possibility of active adjustment of the, for the effect of gravity compensating springs, is seen in the DAS (Exact Dynamics), the Armon Ayura (Microgravity Products) and the Darwing (Focal Meditech, figure 3). The more complex devices are not commercially available at the moment. These devices, often called exoskeletons, intent to mimic all joints of the upper extremity separately. Operation of 7 tongue switches resulted in controlling the exoskeleton at joint level in the older Rancho Electric Arm [15] or by using the movement intentions, measured by Electro Myography and a sensor, in a more recent development of the SUEFUL-7 [16]. A study into using force sensors to distill movement intention in the WREX has, as far as the authors are aware, not led to the development of a commercially available device since [17].

Figure 3. An example of an actively-actuated dynamic arm support (Darwing, Focal Meditech)

IV. DISCUSSION

The aim of this study was to investigate the confusing variety of dynamic arm supports that support arm function in performing ADL tasks. It seeked to establish which devices have been developed and which are commercially available. This search yielded many more devices than originally expected. Half of the 97 devices found was not commercially available in October 2012. The categorization applied is purposely of limited complexity and the following categories were identified: non-actuated, passively-actuated and actively-actuated devices. This overview shows a limited diversity in functioning principles of the devices.

TABLE 1. CATEGORIZED COMMERCIALLY AVAILABLE AND DEVELOPED DYNAMIC ARM SUPPORTS.

	Non-actuated (N=39)	Passively-actuated (N=24)	Actively-Actuated (N=34)
Commercially available[a]	1. Friction controlled MAS 2. Jamie 3. Horizontal M.A.G 4. MultiLink Mobile arm support 5. Standard mobile arm support (MAS) 6. Stanmore flail arm orthosis 7. Suspension mobile arm support 8. Zonco mobile arm valet 9. Arm support roll 10. Armrest 11. EG-Ergoarm ergonomic adjustable computer armrest 12. Ergorest 13. Hemivital-orthese 14. Portable zonco arm support 15. Top 16. True arm rest 17. Zonco arm support 18. Balanced forearm orthosis and Radial arm orthosis 19. Thomas steady arm 20. Suspension sling	1. Wilmer elbow extension orthosis 2. Wilmer elbow orthosis 3. Balancer 4. Armon Edero 5. Mobility arm 6. SeaboMAS 7. Sling 8. Swedish Help Arm 9. X-ar 10. WREX 11. Multilink Mobile arm support – elevation assist 12. Standard MAS with elevation assist 13. TOP/Help 14. Comfy feeder 15. Neater Eater 16. Nelson 17. MAG vertical orthosis	1. Armon Ayura 2. DAS 3. Sling 4. Neater Arm Support 5. Top/Help 6. Darwing
Not commercially available[a]	1. Dynamic triceps driven orthosis (DTDO) 2. Balanced forearm orthosis (1953) 3. Balanced forearm orthosis (BFO) 4. Barker Feeder 5. C-clamp feeder 6. Corset-based feeder 7. Foot-operated feeder 8. Stand feeder 9. Successor barker feeder 10. Successor segmented arm feeder 11. Bird-cage feeder 12. Dynamic mouse support 13. UnterarmschutzeTermi 14. Assistive drawing device 15. Action arm 16. Separate overhead arm –suspension (Middlesex) 17. Separate overhead arm- suspension (JA preston's) 18. Aluminium through 19. Michigan Feeder	1. Assistive device for forearm lift 2. Constant elbow torque orthosis 3. Musgrave orthosis 4. Wheelchair attachable deltoid aid 5. Segmented arm feeder 6. Overhead sling with counterweights 7. Floating arm support	1. Musgrave orthosis 2. SUEFUL-7 3. WREX-active 4. Engen's pneumatic orthosis system 5. Exorob-7 6. Ikerlan'sorthosis 7. Rancho electric arm 8. Gravity Neutral orthosis (GNO) 9. Burke modular upper extremity orthotic system 10. Case research arm Aid, Mark I 11. Case orthosis 12. ESTA 13. Hybrid arm orthosis 14. IRM electric arm orthosis 15. MULOS 16. PODEUM 17. Upper limb motion assist system 18. Wheelchair mobile arm support 19. CEDO 20. WOTAS 21. MAS with powered-assist height adjuster 22. UBC orthosis 23. ARAO 24. Wearable handling support system 25. Reaching movement support 26. A power assisted arm balancer 27. 8 DOF robotic orthosis 28. The mobile arm support

[a.] Note that commercial availability was determined in October 2012. A device was regarded as being commercially available if the authors found the device on a website of a distributor or manufacturer. For a complete list of references please contact the author.

About half of the non-actuated devices are commercially-available. The resulting offer in the market may seem high, but these devices can be fabricated relatively easy, for persons specifically by orthopaedic or rehabilitation centers themselves and are in general less expensive than the other two categories. This results in a high number of devices with sometimes only small variations. Similar devices in functioning principle are found among the commercially available devices and those that are not available on the market. Comparison of functioning principles in passively-actuated devices also showed that very similar devices are found on the market and among those that are not. About two third of the passively-actuated devices can be found on the market.

Of the 34 encountered active dynamic arm supports, only 6 are currently available on the market. We see that this disappointing number can be partly explained by the fact that it is more interesting to publish about the more advanced active devices that are being developed and not available on the market, than the relatively simple non-actuated devices commercially available. In this category, comparison of devices available on the market and those that are not revealed a difference in the designs. Active devices that work as an arm-lift and devices that allow for active adjustment of the amount of gravity that is compensated for are available on the market. All need to be operated actively by the end-users, for example by a switch. Actively-actuated exoskeletons, that mimic the whole arm function, or just a part of the arm, are not available on the market. Some of these prototypes, such as the SUEFUFUL-7 [16] and an active version of the WREX [17], aim to assess the user's intentional movement by for example force sensors and EMG. The application of this technology will be advantageous to the user since devices have not to be controlled by a switch anymore. Such devices acting upon the user's intention, however, are not available to the end-user yet. Maybe these more advanced technologies are not ready to be used by the target population and need to mature first.

For the active devices that not have become commercially available yet, it is unclear whether these devices lack effectiveness, or do not improve the ability to perform ADL tasks. Some seem to be still rather big and therefore they might be impractical to be used at home. Difficulties might still exist in putting the device on and off and in the interfaces used for operation. Another explanation for the high amount of active devices that are not commercially available might be that it is easier to bring non-actuated or passively-actuated devices to the market than the active devices, since higher production costs are expected for active devices, leading to high prices. Making them less affordable for patients or less likely to be reimbursed. It also is remarkable that all active devices commercially available are manufactured in Europe where reimbursement of assistive devices is different than for example in the United States.

Poulson et al. stated that usability issues in Assistive Technology products as well as development of devices that do not meet the needs of end-users were a common problem in the field of Assistive Technology in general [18]. Therefore, user involvement is regarded as being important in the design process. Looking at the field of dynamic arm supports, these kind of problems could hinder the introduction of devices on the market. Increased involvement of the end-user from the first stages of design process and cooperation with parties familiar with the market and the end-user, such as occupational therapists and companies, might increase the likelihood of devices becoming commercially available.

Regardless of the factors contributing to devices not becoming commercially available, a lot of money and effort is spent during the developmental process of active devices. These developments probably do result in increased knowledge in the field of robotics and technology, but seem to fail repeatedly to become available for patients yet. Many articles that do report on the development of an active device actually consider supporting people with upper limb weakness during ADL as an important goal of their research. For end-users to benefit from these developments, it seems more effort could be put in bringing these devices to the market.

Different sources were consulted in order to collect the dynamic arm supports in this study. A wide range of products were encountered, therefore missing any products would probably not have led to different results. Commercial availability was extracted from websites of distributors and manufacturers. Due to information that may not be up to date on websites or could not be found, devices might have been listed in this article as being commercially available, while in fact they were not and the other way around.

V. Conclusion

For the non-actuated and the passively-actuated devices, similar devices are found among both the commercially and not-commercially available devices. For the active devices, however, devices that are not available are different in working principle than the commercial ones. More advanced devices that could be advantageous to the user are not on the market yet. Next to the effort spent on the technical development, more effort should be put in making these devices commercially available so that people with upper extremity limitations can benefit from the newly developed devices.

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