EVALUATION AND ADAPTATION OF A NON SINGLE LENS REFLEX CAMERA FOR USERS WITH MANUAL IMPAIRMENTS

by

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Thesis submitted to the Faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Industrial and Systems Engineering

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August, 1994

Blacksburg, Virginia

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(ABSTRACT)

The accessibility of consumer products is an issue for many people with special needs. This study addresses the usability of non-single-lens reflex (NSLR) cameras for people with limited hand grip strength and finger dexterity, namely people with quadriplegia or people with arthritis. It proposes a three-phase methodology to eliminate or mitigate accessibility barriers on a consumer product.

A usability test was conducted with a NSLR camera. Problems were recorded with the Critical Incident technique. Prioritization of the problems reported by the subjects show that the shutter release control and the camera grip are the two major accessibility barriers of the product.

Four new camera models were developed: three with gripping aids (rubber pads, a thumbsleeve, or a handle) and one with a remote wired shutter release control. A fifth model was obtained by combining the remote shutter release control and the handle.

A designed experiment was conducted with the five models and the standard camera. Performance measurements of framing tilt and camera shake were collected, as well as subjective opinions. Results indicate a recurrent difference between performances of quadriplegics and perfrormances of other subjects. The remote shutter release control was shown to eliminate accessibility barriers. The handle also increased ease of grip and camera stability for disabled subjects.

ACKNOWLEDGMENTS

I would like to thank the members of my committee: Dr. Robert Williges for his support and patience, Dr. Karl Kroemer for his advice, and Cathy Daniels for her invaluable help and supervision during my stay in Rochester, NY. I would also like to thank all the members of the Human Factors Laboratories at the Eastman Kodak Company. for their advice, and Ken Smithborne who developed the camera models. I would like to thank the Woodrow Wilson Rehabilitation Center and the Genesee Chapter of the Arthritis Foundation for their help in recruiting subjects. Lastly, I would like to dedicate this master's thesis to my father, Dr. François Davoine. Without his support and his respect of the American educational system, I could not have completed my degree at the Virginia Polytechnic Institute and State University.

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INTRODUCTION

Consumer products in our society are mostly developed for an average range of users. When a decision is made about the design of a feature on a product, the usual rule is to choose a solution that is acceptable to 90% of the population. This is done in general by designing the product to fit users from the 5th percentile female to the 95th percentile male. However, by doing so, designers ignore those who lie at the extremes of the population. Users with special needs are users who, for some reason, find themselves in the tails of the bell curve of the normal distribution of a physical, sensorial, or psychological variable. Users with special needs include, but do not consist exclusively of, the elderly and people with disabilities. These people have to struggle with many products whose designs exclude them from the consumer population. Research in human factors and other fields such as rehabilitation engineering has acknowledged this problem and tried to enlarge the user populations of consumer products.

Cameras are a common consumer product. Over 16 billion pictures are taken in the United States every year. To satisfy as many consumers as possible, cameras take many forms and use many technologies. A segment of the market is targeted by compact non-single-lens reflex (NSLR) 35 mm cameras. These cameras have in common that they do not require any manual focusing. Most of them are small enough to fit in the hand or in a pocket. Taking a picture with these cameras, although a common action for many users, still requires a number of manual capabilities. These cameras were designed for the mass market, and, therefore, people with hand impairments might have difficulties using them. This research is concerned with uncovering and mitigating the problems that people with hand impairments might encounter when using a small NSLR camera.

Literature Review

Very little literature was found on the specific problem of adapting cameras for users with special needs. However, many studies and articles relate to the more general topics of people with special needs and of designing consumer products for these users.

Data on People with Special Needs

No exact definition of users with special needs seems to exist. The general consensus seem to be that they are people at the extremes of a population. However, most studies deal with one or both of the following populations: people with disabilities and the elderly.

Therefore, the literature review for this study was principally directed towards these populations.

Research in designing for people with disabilities is hampered by the lack of valid and usable data on this population. Each organization dealing with people with disabilities has its own definition of disability. The polling systems used are not compatible with each other (Kirchner, 1990). A workshop held in 1990 by the Committee on National Statistics assessed the problems due to this inconsistency (Levine, Zitter, and Ingram, 1990) and recommended the creation of a panel to address the problem more thoroughly.

According to the results of the 1990 Census, about 22.4 million American people aged 16 and over have a work disability (preventing them from working or impairing them in their work), a mobility limitation, or a self-care limitation. Because of a different definition of 'disability', the Americans with Disabilities Act (ADA) counts 43 million Americans with disabilities. This takes into account people with mental and emotional disorders. The ADA, passed in 1991, was a very important law for people with disabilities. It increased the awareness of the population of some problems that people with disabilities have to deal with. As a result of the ADA, people with disabilities will be able to obtain access to public areas and buildings as well as jobs. As their role in the community increases, their struggles with theenvironment are noticed by more companies and manufacturers.

At the end of the eighties, about 12% of the population in the United States, representing about 30 million people, was aged over 65. This percentage is projected to reach 21% by 2030, which will represent more than 64 million people (data from the US. Bureau of Census, found in Spence (1989)). This phenomenon, commonly known as the graying of the population, has triggered many new interests for the elderly as a market segment. Books are edited (Buck, 1990; Koncelik, 1982), companies created, articles printed in various journals, that are concerned uniquely with designing, developing, and manufacturing consumer products for the elderly.

Designing for People with Special Needs

Designing products and environments for people with special needs is not a new field. In 1974, Chapanis was already calling to human factors professionals for more research in this field. The Independent Living movement, born in the seventies, triggered projects in architecture (Lifchez, 1987). However, it is not until recently that guidelines for the development of products for populations with special needs have been published.

Guidelines. Three main sets of guidelines were found in the literature: the guidelines by Vanderheiden and Vanderheiden (1991), a Honeywell, Inc. report written by Isle, Denno, and Metz (1992) and the work by Pirkl and Babic (1988). Research by Charness and Bosman (1990) on human factors and the elderly could, in some case, be used as guidelines.

Since all these documents originated from independent projects, they differ in regard to the populations they consider, and the way their guidelines are organized and quantified. Table 1 shows how the three major sets of guidelines, Pirkl and Babic (1988), Isle, Denno, and Metz (1992) at Honeywell, Inc., and Vanderheiden and Vanderheiden (1991) compare along those dimensions. The levels of specificity given in this table are actually the authors' objectives for their guidelines, but in reality, within a document, the level of detail from one guideline to another can vary greatly from being a vague recommendation to citing quantified data supported by empirical research. Most of the guidelines are incomplete, and call for more research.

Although these documents do not seem to directly contradict each other, it is difficult to compare their content because of their differences in presentation, quantification, and targeted populations. It is therefore difficult to summarize them into one essential set of guidelines.

Related Research. Other research has been conducted that usually concentrated on a particular element of an interface and/or on a particular disability. Such work has been done for example by Kanis (1993), Metz and Isle (1990), and Voelz and Hunt (1987) on the effects of control characteristics, mainly for control knobs, on the use of products by people with arthritis and hand disabilities. Steinfeld and Mullick (1990) looked at interactions of people with arm and hand impairments, mostly quadriplegics and arthritics, with different products and architectural environments. Studies were also conducted to obtain anthropometric measurements of population with special needs. Hobson and Molenbroek (1990) collected data on seating anthropometrics of people with cerebral palsy. Floyd, Guttman, Noble, Parkes, and Ward (1966) examined reach ranges and space requirements of subjects in wheelchairs. These studies provide rare information. Most anthropometric studies are in fact conducted on college students or military personnel, where users with special needs are not present.

Other research has focused on the elderly and their use of consumer products. Koppa, Jurmain, and Congelton (1989) looked at improving the design of a refrigerator for elderly users. In another study (Bordett, Koppa, and Congelton, 1988) forces of elderly people were measured when using different types of faucets. Imrhan and Loo (1986) measured forces and torques exerted by elderly as well, when opening screw top containers. These studies have in common results that show how the design of a device can exclude an elderly person from its user population.

Table 1. Comparisons of the Objectives of Three Main Sets of Guidelines

Guidelines	Pirkl and Babic (1988)	Isle, Denno, and Metz (1992)	Vanderheiden and Vanderheiden (1991)
Targeted population	Elderly	Elderly and people with physical or cognitive disabilities	Elderly and people with physical or cognitive disabilities
Guidelines classification	By sensory and physical factors: Vision Hearing Touch Movement	By product components: Controls Visual displays Graphics Auditory displays Panel layout Operating protocol	By functional categories: Output/Displays Input/Controls Manipulations Documentation Safety
Level of preciseness	Design strategies. No numeric values or data.	Recommended value, based on research, for each parameter of the product component.	Design options and ideas are given for each problem, with recommended values for parameters when available.
Guideline presentation	Specific physical or sensory disorder, physical change, functional effect, problem(s), design guidelines and strategies. (Organized in a chart)	Appropriate application of the component, parameters of the component.	Objective, problem statement, design options and ideas to consider, additional information. Eventually real world examples.

Obstacle. A lack of communication among fields dealing with people with disabilities has been pointed out in the literature (Kondraske, 1988). This makes the achievement of design projects more difficult. Taxonomies have been developed separately, without worrying about correspondence. A physician, an ergonomist, and an occupational therapist, for example, could be talking about the same patient in different terms, without being able to translate reliably one description into another. Figure 1 illustrates this problem. Each person considers the patient in a different way, depending on his or her objectives. Problems occur when they try to communicate. For example, there is no table giving the forces a subject can exert, or what activities of daily living this person could perform, when diagnosed with arthritis.

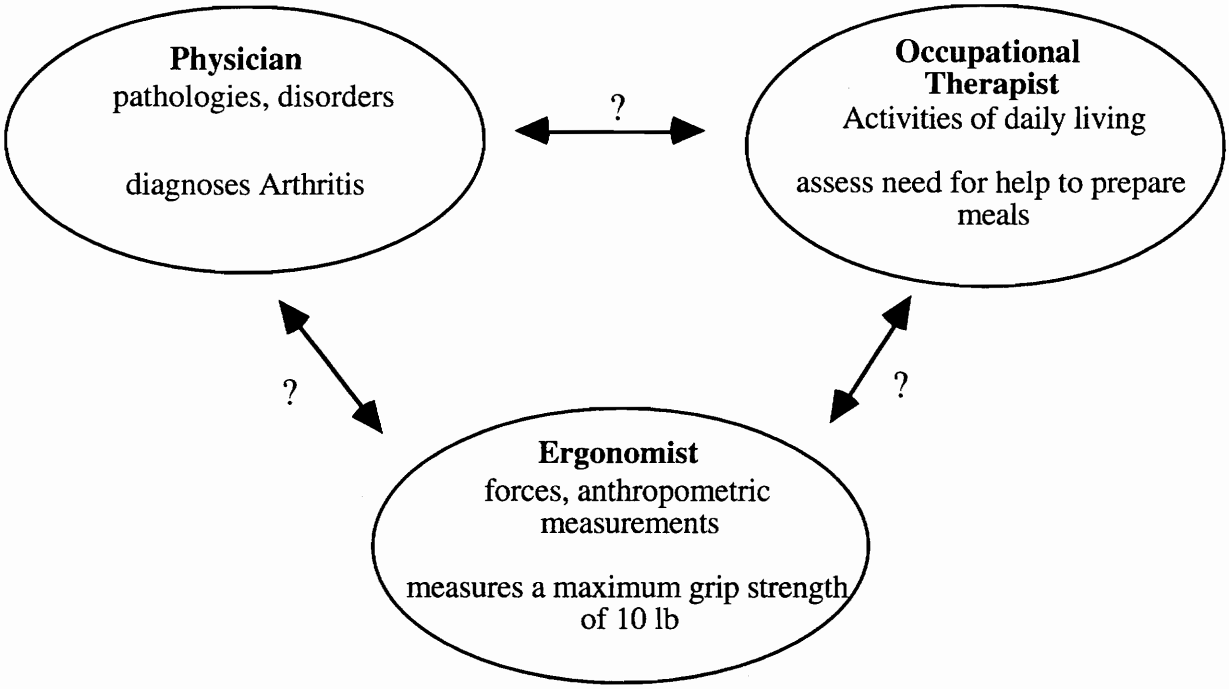

Figure 1. Examples of Different Ways of Describing an Individual with Disabilities

Some attempts have been made to overcome this problem. In their guidelines, Pirkl and Babic (1988) tried to associate physical disorders first to the functional limitations patients encounter and second to adequate design strategies. For example, loss of muscle tone causes loss of finger, hand, and wrist strength and endurance, and therefore, needs for rotations, twists, and grasps should be minimized.

<u>Approaches</u>. There are different approaches possible when designing for populations with special needs. Vanderheiden and Vanderheiden (1991) distinguishes four of them:

- facilitating custom modifications
- compatibility with a third-party assistive device
- accessible options or accessories provided by manufacturer
- direct accessibility, that is, designing the product to be accessible without the need for any additional device

These approaches are listed in order of increased desirability according to the authors. The two last approaches put the responsibility of the accessibility of the product entirely on the manufacturer. The last approach has also the advantage not to distinguish the users with disabilities from others, which is particularly appreciated by the elderly. However, direct accessibility might not always be possible to obtain, given the complexity of consumer products, nor profitable, and therefore, a tradeoff has to be sought in most cases.

Methods. A literature review was conducted to find what type of methodology is used when studying people with special needs. Using people with special needs throughout the entire design process of the product seems to be the most popular method currently employed in studies directly concerned with the development of a product. In some cases, users participate simply through usability testing, and general usability methods are applied (Benktzon, 1993). Sandhu (1993) describes a different approach. In his studies, user panels evaluate multiple comparable products at the same time. Users are asked to go over a checklist, examine all tasks necessary to use the product, and report the problems they meet. Both authors stress the importance of involving users with special needs as early as possible in the design process.

Kondraske (1988) presents an interesting method, based on a system approach, to solve problems at the interface between a user with disabilities and his or her environment. However, this approach, which might be successful in rehabilitation engineering, is geared more towards solving the problems of an individual, than trying to adapt a product to as many users as possible.

Studies aimed at answering a specific research question, such a comparing knob sizes, (Voelz and Hunt, 1987), or torques required to unscrew jar tops (Imrhan and Loo, 1986), use designed experiments. However, usual research methods cannot always be applied without being reviewed or adapted. An article by the Institute for Consumer Ergonomics (1981) points out some of the obstacles experimenters might encounter. Subjects are harder to recruit, since drawn from a sub-population with specific characteristics. Specialized organizations, such as a retirement community or a rehabilitation center, can be very helpful, but these are not available everywhere. Mobility disabilities of the subjects limit also the possibilities for the location of the experiment. Often the researchers must go to the subjects instead of letting the subjects come to them. Equipment might not fit the unusual postures of subjects or might not be reliable enough when extreme values are to be measured. The apparatus might be inappropriate for people with very low pain thresholds as in the case of arthritis patients, raising thereby ethical issues.

The analysis of the results also requires greater attention. Sample representativeness and normality assumptions in particular must be checked. The literature (Hobson and Molenbroek, 1990; Lawton, 1989; Institute for Consumer Ergonomics, 1981) calls for a greater care than usual on these issues when using elderly or disabled subjects, and underlines the importance of selecting the correct research methods and statistical test. This topic has become so important that, in fact, the Center for Gerontology at Virginia Tech even offers a special seminar on research methods in gerontology, helping students to deal with these problems.

Hand Impairments.

Data. Exact data on the number of people suffering of hand impairments and who therefore could benefit from this research could not be found in the literature. Many disorders and diseases can reduce hand abilities. For example, certain stages of multiple sclerosis and muscular dystrophy, which are progressive diseases, will affect hand abilities. Some types of Parkinsonism can cause tremor in the hands. However, the two largest causes of hand impairments are probably arthritis and quadriplegia. There are an estimated 30 to 40 million people with arthritis in the United States (Spence, 1989). In fact, 80% of people in their 70's are affected by arthritis. With the graying of the population, this number is expected to increase. However, arthritis is a disorder that can affect any joint of the body, and no figure could be found about how many people suffer from arthritis specifically in the hands. In 1983, there were 80,000 to 93,000 people with quadriplegia in the United States, but the number of quadriplegics too severely disabled to manipulate a camera with their hands is unknown.

Results from the 1990/1991 Survey of Income and Program Participation indicate that 8.3% of the population , or 16.2 million persons, have difficulties "lifting and carrying 10 lb.". Although this is clearly an overestimation of the number of persons that could be interested in a camera designed for people with manual impairments, since NSLR cameras weigh typically 2 to 3 lb., it is the best approximation that could be found. Besides, the number of persons benefiting from an accessible camera should be continuously changing, as people are sometimes temporarily disabled (e.g., someone with a broken arm). In addition, other factors besides weight affect camera accessibility.

Assessment of Hand Functions. When designing a product accessible to users with manual dysfunctions, assessing the hand functionalities of the users is necessary. Evaluating hand abilities is mostly used in the clinical environment, to check the effectiveness of a treatment, and by occupational therapists. The literature in this field shows that two approaches are possible: a biomechanical or a psychosocial one. In the first case, measurements of forces, torques, or times are taken, providing normative and objective data. In the psychosocial approach, also called behavioral approach, observations of how and how well a patient can achieve certain tasks are collected. In this approach, subjective evaluation by the patients themselves is of large importance.

Measurements of hand impairments are taken along different dimensions. The two most important ones are grip strength and finger dexterity. Power grips are usually evaluated with a dynamometer and pinch grips are measured with a pinch meter (Smith, 1973). Definitions of these grips are given in Kroemer (1986). The most common way of evaluating a subject's dexterity is the use of peg boards (Mathiowetz, Weber, Kashman, and Volland, 1985; Okada, 1985), although other tasks, such as displacing objects on a table from a specified point to another or lifting small weights, are used (Clay, 1987). Some assessment methods combine both approaches and both dimensions by using various evaluating tasks (Smith, 1973). Other methods are developed for a specific population, such as in the study completed by Jones, Unsworth, and Haslock (1987) for people with rheumatoid arthritis. There seems, however, to be no standard evaluation method and no consensus among the rehabilitation community on which methods to recommend. Each institution uses what seems to be the most convenient to them.

The psychosocial approach uses Activities of Daily Living. The patient usually goes through a checklist of various daily tasks with a therapist who notes if the patient can perform each task independently, with assistance, or not at all (Hopkins and Smith, 1978). Here again, no consensus was found on the exact activities to consider, or a standard way of reporting the patient's data.

Camera Design

When redesigning a product, or at least adapting it, it is important to understand the original design. The evolution of the design of cameras and the documents used by designers are valuable sources of information. Most of the large companies, such as Eastman Kodak Company, have internal human factors guidelines for their products (Human Factors Group at Eastman Kodak Company, personal communication, January 24, 1994). However, these documents do not consider users with manual impairments.

As far as designing cameras for people with disabilities, only a project done by Polaroid to adapt one of their cameras with a pistol grip and a wheelchair camera has been found in the literature (Scalingi, 1991). However, this article does not describe the type of research conducted by Polaroid to select these adaptive devices.

Major Emphasis

Among the different approaches to designing accessible products, as described by Vanderheiden and Vanderheiden (1991), two will be considered in this study: (1) having a product directly accessible, without the addition of a device, and (2) having the manufacturer provide the necessary accessories to make the product accessible.

Before starting any experiment with subjects with disabilities, it is very important to specify exactly who will be tested, since the term "disabled" includes a large variety of persons possessing a large variety of abilities. This study intends to deal with people with hand impairments; however, this is still too vague as there are multiple types of hand impairments. Only two impairments were selected for the proposed experiment: strength and dexterity limitations. Tremor or problems due to missing fingers or hands were not evaluated, mainly because they are less frequent and because there is very little existing literature on these impairments. On the other hand, grasping and strength limitations are more frequent, partly because this is what arthritis causes. The objective of this research is to enlarge the user population of a camera, not to adapt the camera for all users. Therefore, people with no hand abilities were considered in the research. Subjects will have to be able to at least lift a camera up to eye level.

The modifications or additions to the camera have to be kept simple. There would be no sense in developing an expensive accessory for a simple NSLR camera. Some characteristics of the camera, such as its shape and size, are not modifiable. Those technical limitations had to be discussed with camera designers and engineers.

Purpose of Study

The purpose of the study described in this thesis is to identify barriers posed to users with manual impairments by NSLR cameras and to evaluate the effects of different adaptive devices designed to reduce these barriers. The devices could be either included in the design of the camera or attached to the camera.

The literature review examines previous research in the field of designing products accessible to users with special needs. It also points out that more techniques and methods should be available to researchers or designers interested in this area. There seems to be no complete methodology previously developed to answer accessibility problems of users with special needs dealing with consumer products. Therefore, this study proposes a new methodology, based on methods used for other research in this field, but also on other well-known techniques. The study examines the assumption that people with hand impairments currently meet specific accessibility barriers with NSLR cameras, resulting in bad picture quality, and tries to eliminate barriers for these users, by identifying the barriers, generating new designs of the product, and evaluating these new models. There are four null hypotheses for this research:

1. Picture quality is the same regardless of if the camera was adapted or not.
2. Subjective ratings of the cameras do not show any preference for the adapted cameras over the standard model.
3. The level of hand impairment is not related to the objective quality of the pictures.
4. The level of hand impairment does not have any effect on subjective camera ratings.

METHOD

Methodology

A three-phase methodology is used in this study. It results from the combination of other human factors experimental methods and principles, put together to optimize design of a consumer product accessible to users with special needs. Although the methods used here have been applied to many other studies, no documentation was found about their use when subjects with disabilities are involved. Therefore, the methodology proposed is new, in the sense that it adapts these methods to a new problem. The objective of this specific study is to increase accessibility of a small NSLR camera for users with manual impairments. However, the methodology was developed to be applicable to any similar problem, and is therefore described here in the more general framework of adapting any consumer product to a sub-population of users with special needs. The specific methods used for this research will be discussed in following sections. The three major phases of the study are to identify accessibility barriers, design alternative solutions, and verify the elimination of barriers in these new solutions.

Phase I

The major purpose of the first phase of the design is to identify the accessibility barriers present on the consumer product or type of products. The first two steps in doing so are to define the sub-population of people with special needs to study, and select the product or type of product. Adapting a product for users with special needs is a large and complex problem given the diversity of disabilities existing. To limit the complexity of the research, only a subgroup of disabilities should be considered when applying this methodology. The product to be evaluated should be selected so that it can be easily modified, since new prototypes of the product will be needed in the following phases. A task analysis of the product should also be available.

Once the population of interest and the product to be evaluated are selected, the interface between one and the other will be tested, to identify where barriers occur. According to the recommendations found in the literature (Benktzon, 1993; Sandhu, 1993), users with special needs should be involved as much as possible in the design of the product. Therefore, usability testing by subjects drawn from the population defined earlier is essential in Phase I. Suggestions and comments of subjects are also primary sources of information that need to be collected. Subjects tested should not only be people with disabilities, but also people without disabilities. Since the purpose of this research is to design a consumer product accessible to users with special needs, and not a device for these users only, all categories of potential users of the product must be present in the usability testing.

The results of Phase I will describe the barriers met by subjects, give the frequency of each problem, and explain the effects of each failure on the use of the product. Determining which element of the product was a problem for which group of subjects tested is important for the rest of the study as well.

Phase II

The purpose of Phase II is to try to eliminate the problems identified in Phase I. This implies the need to redesign or redefine the product. Phase II is the phase during which collaboration with other professions is essential. Industrial designers, engineers, or technicians familiar with the product must be involved in this phase. The techniques used must therefore be compatible with their own principles and techniques, but must be used to benefit as much as possible the needs of users with disabilities, which these members of the design team might not be familiar with.

Selection processes are likely to take place at different stages of Phase II. Indeed, many solutions might exist to every problem identified in Phase I. Realistically, only a few can be implemented. Time and money constraints will reduce the number of designs that can be developed. Furthermore, efficiency of the solution might vary from one design to another (e.g., some models might be perfect for only a restricted subgroup of the population studied). User's input and other selection techniques will be necessary again.

Phase II should lead to the design of selected potential alternatives to the product chosen at the beginning of Phase I. These alternatives should be developed so that they can actually be evaluated by users in Phase III.

Phase III

Evaluating the alternatives developed in Phase II, and selecting the ones that do eliminate accessibility barriers, are the purposes of Phase III. By the end of this phase, modifications increasing the usability of the product for the population selected at the beginning of Phase I should be recommended. An experimental design must be conducted from that perspective, where performance measurements are taken with the alternative products with the original one used as a control condition. In addition, as in Phase I, subjective opinions and suggestions must be collected, so that input from users is present throughout the design process.

Comparing of the different alternatives with the current product will allow for completion of the objective of the research: the design of a consumer product accessible to people with special needs. Careful step by step progression through Phase I and Phase II should lead to significant results in the designed experiment of Phase III.

General Procedures

Although different methods are used for each of the phases of the methodology, some procedures are general to the entire study. Subjects were always presented an informed consent form to sign prior to any testing. This consent form contains descriptions of the study and of the benefits and risks of participating in the study. Subjects are also reminded that they have the right to leave the experiment at any time for any reason without penalty, and are given the names and phone numbers of the people in charge of the study in case they have complaints. The exact procedure of the session was explained in another attached form. The informed consent form for the usability testing of the first phase is shown as an example in Appendix A. Only minor details and the procedure form attached were changed for the third phase.

In all experiments throughout the study, questionnaires were given to the subjects to collect subjective opinions and comments. Although their content differed from one phase to another, they were developed with special care, to avoid any confusion and to require short answers as much as possible. Where rating was necessary, Likert scales were used. Since some of the subjects had difficulty writing, all subjects were read the questionnaires out loud and had to give their answers orally. This approached helped the subjects and avoided any confounding effect on the way the questionnaires were distributed by treating all subjects equally.

Subjects received a compensation for their participation in the study. In most cases, a single use camera was given to them. When subjects could not complete the entire session for some reason, rolls of films were given instead.

PHASE I

The three main steps of Phase I are to define the population that should be tested, define the product that will be adapted, and conduct a usability test.

Method

Population

For the purpose of this research, the population of interest has already been reduced to people suffering from hand impairments. However, many types of hand impairments exist, causing different types of disabilities and accessibility problems. Therefore, the population was narrowed down further and only two types of hand impairments will be studied:

- Hand grip strength limitations, which should imply problems in gripping a camera and stabilizing it at eye level, as well as pushing on the shutter release control. Problems should also appear when loading a film.
- Finger flexibility limitations (or finger stiffness), which should imply problems in obtaining a good grip on a camera, efficient enough to lift the camera without obstructing the lens while still being able to reach the shutter release control. The task of loading a film should also be more difficult with stiff fingers.

It is difficult to isolate hand impairments one from each other. Most often finger stiffness comes with strength limitations, and sometimes tremor. Finding groups of subjects suffering only from one of the impairments considered in this study is, therefore, unrealistic. Selecting conditions that subjects suffer from is easier than selecting people on the base of impairments. Two conditions that cause grip strength limitation and finger stiffness are arthritis and quadriplegia. Other human factors studies on people with hand impairments have recruited subjects with these conditions in the past (Kanis, 1993; Voelz and Hunt, 1987; Steinfeld and Mullick, 1990). However, the severity and exact type of dysfunctions caused by these disabilities are different. Arthritis is due to joint degeneration while spinal cord injury implies nerve dysfunction. The usability problems people with each condition encounter when using hand-held products might therefore be different as well. It was decided that arthritics and quadriplegics will be tested separately in two distinct groups.

Hand impairments occur when arthritis is located in the finger knuckles or in the wrist. When the knuckles are inflamed, the hand cannot be tightened in a fist anymore, reducing gripping abilities of small objects in particular. When joint degeneration occurs in the wrist, bending of the wrist becomes painful, and objects can therefore be gripped only in certain positions. Deformations of the hands also reduce gripping abilities. Hand impairments of quadriplegics are due to the section of the ulnar and the median nerve which innervate the hand. These loss of innervation results in no or very little strength in the hand, and no or little finger dexterity depending on the level of the spinal cord injury. Quadriplegics with a complete C5 injury or a higher injury have no hand nor wrist functions.

Cognitive abilities, which are correlated to age, are involved in the use of a camera. Therefore, age should be controlled as an independent variable. Arthritis is a common disability among elderly people, whereas a majority of quadriplegics are young people under forty (Ficke, 1991). Splitting subjects with disabilities in different groups according to their conditions makes it thereby easier to control the age effect. Two control groups of younger and older adults were used in the study. The age of 50, often used in marketing, was chosen to separate the two groups. Quadriplegics were also selected to be under 50 and arthritics to be over 50, so that confounding of the age and disability effects were avoided.

Subjects

Subjects with disabilities were required to have at least the ability of lifting a small camera to eye level. This eliminated any quadriplegic suffering of a complete C5 injury or higher. Subjects with disabilities were also required to have problems when performing at least one out of a group of selected Activities of Daily Living (ADL), to differentiate them from the non-disabled population. This list of ADL can be found in the questionnaire in Appendix B. Hand measurements of grip strength. pinch strength, and manual dexterity were also taken to verify differences in manual abilities.

In a recent study, Virzi (1992) concludes that 80% of usability problems are detected with four or five subjects. With six subjects, all highly severe problems are uncovered. Therefore, six subjects were to be tested in each group. Subjects were recruited in the Blacksburg, VA area, except quadriplegics, which were recruited and tested at the Woodrow Wilson Rehabilitation Center in Fisherville, Va. Subjects with arthritis were particularly difficult to recruit in the Blacksburg area. Because of time constraints, only five subjects from this group participated in this phase of the study.

Camera

The camera selected for this study was chosen for its general ease of use and its representativeness of small compact 35 mm NSLR cameras found nowadays on the market. These cameras are commonly called "point and shoot" cameras. The shutter release control is the only control on the camera, and is located on the top right. The camera has an automatic advance and a flip-up flash that protects the lens when closed. An LCD on top of the camera displays the number of frames remaining on the film, the flash status, and the battery status. The camera belongs to a family of products, all similar in design. Only features and electronics vary from one camera to the other.

Apparatus

Hand measurements were taken on all subjects. Their hand grip strength, pinch strength, and manual dexterity were measured on both hands with respectively a dynamometer, a pinch meter, and a peg board. The dynamometer and pinch meter were borrowed from the ISE Assessment Laboratory at Virginia Tech, and the peg board was built according to the dimensions given by Mathiowetz et al. (1985).

Procedure

Subjects were given an informed consent form to read, as well as a description of the procedure of the experiment, found in Appendix C. Their hand grip strength, pinch strength, and manual dexterity were measured, before they were asked to test the camera.

Usability testing is essential in Phase I to get users' input about what elements of the camera are barriers. Testing was based on the task analysis of the selected NSLR camera. This task analysis can be found in Appendix D. The participants were asked to perform the four following benchmark tasks:

Task 1. Load a roll of film in the camera.

Task 2. Open the camera flash.

Task 3. Take at least three pictures using the viewfinder.

Task 4. Close the flash.

Unloading the film was not required for practical reasons. Subjects would each have had to shoot an entire roll of film. It was speculated that some subjects might not be able to perform all tasks because of the hand strength they required. In these cases, the observer was allowed to help them, so that they could move to the next step. The third task included repeated picture taking to test not only the tasks of grasping the camera and lifting it, but also the task of keeping the camera stabilized at eye level.

Many techniques exist to collect data in a usability test. The Critical Incident Technique, described by del Galdo, Williges, Williges, and Wilxon (1990), is one of them. It was selected to be applied in this study, because it can be applied to any sort of product, and it allows collection of not only failures, but also successes of the product. Furthermore, it is easy to implement and does not require any particular equipment.

A critical incident occurs when a user interacts with a particularly satisfactory feature of the product or a particularly problematic one. When reporting such an incident, subjects are asked to provide three categories of information:

- The type of the critical incident: does it concerns a satisfactory feature of the product or a problematic one?
- A description of the incident: what happened exactly?
- A rating of the severity of the incident on a scale from one to seven, one being "extremely not severe", seven being "extremely severe".

Subjects were asked to report critical incidents orally as these occur. However, they were prompted to report an incident after each benchmark task, if they had not expressed anything during the task performance. They were also given a handout, shown in Appendix C, explaining in detail the procedure, the Critical Incident Technique, and what they were expected to do.

Other data collection methods were used in the usability test. Subjects were videotaped to record their hand positions as they gripped the camera, and their reactions to some of the camera's elements. These were also noted by the observer. Subjective evaluations of the camera were also recorded. Seven point Likert scales were used to ask the subjects to rate how easy the camera was to use, grip, and stabilize, how easy it was to load a film, to open the flash, and use the shutter release control. An overall rating of the camera was also asked. These scales and the additional questions asked to subjects can be found in Appendix B.

Results

Organization of the results of Phase I is particularly important, since they must be presented to members of the design team, and they must allow identification of all accessibility barriers of the product.

Critical Incidents

The problems encountered with each element of the camera, their frequencies, and their severity ratings were obtained from the critical incidents reported by the subjects. Severity ratings for each problem were obtained by averaging the severity ratings given by subjects who reported the problem as a critical incident. These results are summarized in tables and Impact Analysis graphs. The method of Impact Analysis, described by Whiteside, Bennet, and Holtzblatt (1988), aims at presenting usability problems to developers in a Pareto diagram that shows what impact an implemented solution for each problem would have on the total product usability. In their example, the authors used time spent by the users on errors as a dependent variable. In the case of this study, cumulative frequency of the problems were used instead. Results are presented group by group to underline the barriers specific to each group.

Younger Adults. A total of 28 incidents were reported by the six subjects of this group. The complete list of these can be found in Appendix E. Frequencies and severity ratings of the 12 failures are shown in Table 2. The most frequent problem in this group was inserting the roll of film in the camera. Five subjects out of six reported it as a critical incident with an average severity rating of 3.6. Other incidents involved the flash and the absence of framing lines in the viewfinder. Only one subject expressed concern about the fact that the shutter release control (SRC) was too flush with the camera and therefore easy to lose. These results are also presented in the Impact Analysis Graph in Figure 2.

Table 2. Failures Reported by Younger Adults

Problem	Frequency	Average Severity Rating
Inserting the film	5	3.6
Opening the flash	2	4
Framing with the viewfinder	2	2.5
Closing the flash	1	5
Using the viewfinder	1	4
Locating the SRC	1	2

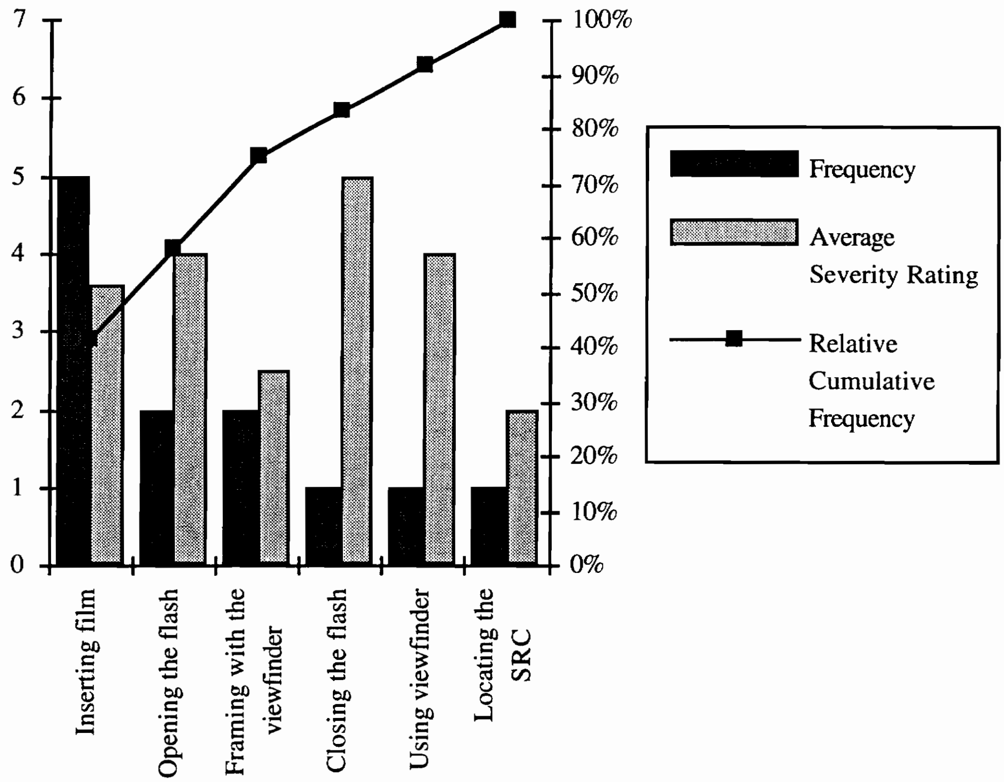

Figure 2. Impact Analysis Graph for Younger Adults

Older Adults. The six subjects of this group reported 15 failures and 22 successes, which are detailed in Appendix E. The problems are shown in Table 3. Inserting a roll of film in the camera was still the most frequent problem for this group. However, subjects in this group experienced different problems than the younger subjects. Four subjects had trouble finding or opening the film door latch. They suggested that the latch should be bigger and color coded. Finding the latch was rated as the most severe problem with a 4.33 average. Similar problems were reported three times with the flash latch. As can be seen in Figure 3, problems with inserting the film, finding the film door, and finding the flash opening system constitute about 70% of all failures reported by the subjects of this group.

Table 3. Failures Reported by Older Adults

Problems	Frequency	Average severity rating
Inserting a film	4	3.25
Finding the film door latch	3	4.33
Finding the flash latch	3	2.33
Charging the flash	2	1.5
Pushing the SRC	1	4
Framing with the viewfinder	1	3
Opening the film door	1	2

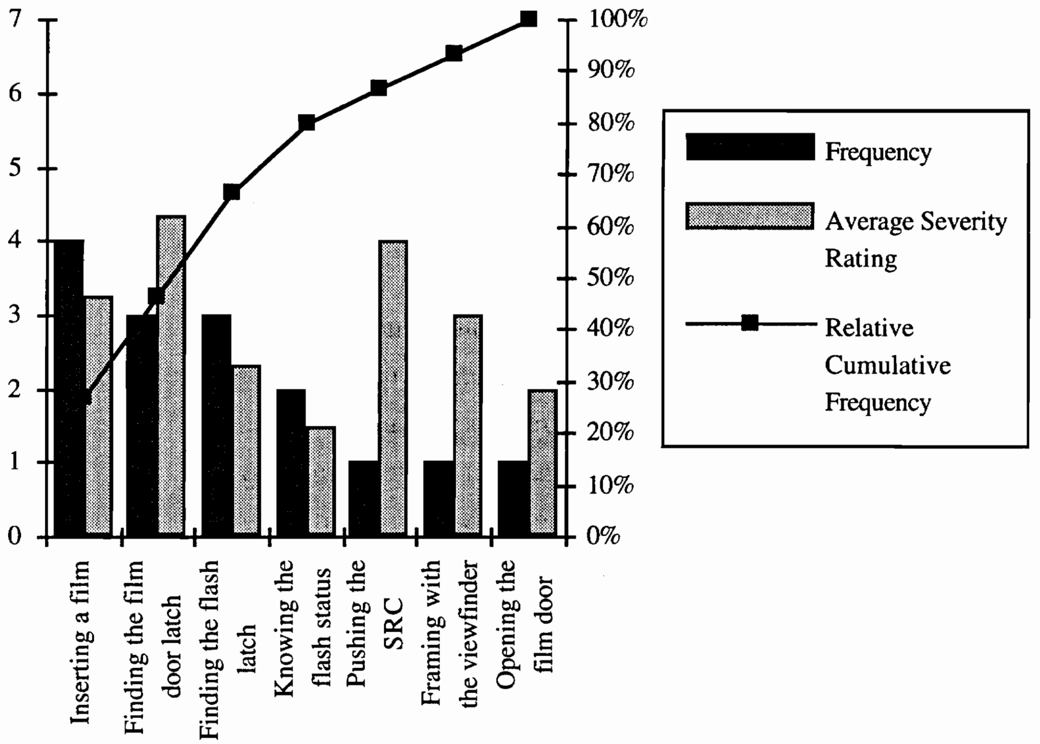

Figure 3. Impact Analysis Graph for Older Adults

Quadriplegics. Levels of subjects' spinal cord injuries varied from incomplete C5-C6 to incomplete C7-C8. All subjects were able to perform all the tasks, but the average time taken to accomplish them was longer than for other subjects. Subjects in this group reported 15 failures, listed in Table 4, out of 32 incidents. The detail of the ratings and descriptions of the incidents can be found in Appendix E. In general, the severity ratings given by quadriplegics are higher than in other groups. However, inserting a roll of film in the camera was rated with an average of only 2, lower than the rating given by non-disabled subjects. Opening the film door was a problem for five subjects out of six. The latch was found too small, and not outstanding enough. New barriers appeared when testing this group. The shutter release control was indeed reported four times as a failure, either because it was too hard to push or because of its location. Severity ratings are high for these two problems, which were both given a rating of seven in severity by at least one subject each. Gripping the camera was also reported twice by quadriplegics, a problem that was not reported by any subject without disabilities. The incidents with the grip on the camera were rated with a 4.5 severity average. Subjects found the camera too smooth and slippery. Figure 4 indicates that 80% of the incidents occurred in opening the film door, loading a film, gripping the camera, and pushing on the shutter release control.

Table 4. Failures Reported by Quadriplegics

Problems	Frequency	Average severity rating
Opening the film door	5	3.8
Pushing the SRC *	3	4.67
Gripping the camera	2	4.5
Inserting a film	2	2
Reaching the SRC *	1	7
Opening the flash	1	4
Finding the film door	1	4

* These two problems received severity ratings of 7 from one subject each

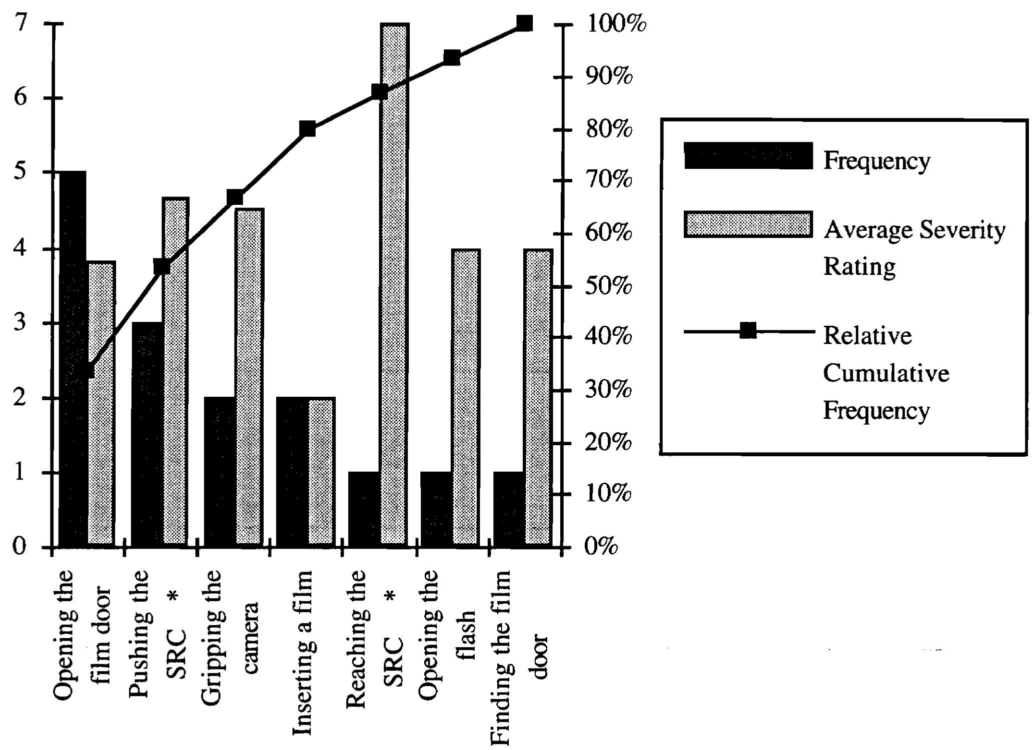

Figure 4. Impact Analysis Graph for Quadriplegics

Arthritics. Only five subjects were tested in this group because of recruitment problems in the Blacksburg area and time constraints. The subjects reported 31 incidents which detailed description can be found in Appendix E. The camera failures are shown in Table 5. Loading film in the camera is still a frequent problem, as for the groups of people without disabilities. However, opening the film door and holding the camera also caused problems to the subjects of this group, but to a lesser extent than to quadriplegics. Arthritics rated these problems as less severe than quadriplegics did, by more than a point. Figure 5 is the Impact Analysis graph of the failures reported by this group, indicating that 83% of the problems of the five subjects of this groups occurred in opening the film door, inserting the film, gripping the camera and locating the shutter release control.

Table 5. Failures Reported by Arthritics

Problem	Frequency	Average Severity Rating
Inserting the film	3	3
Opening the film door	3	2.67
Gripping the camera	2	3.5
Locating the SRC	2	1.5
Opening the flash	1	2
Framing with the viewfinder	1	3

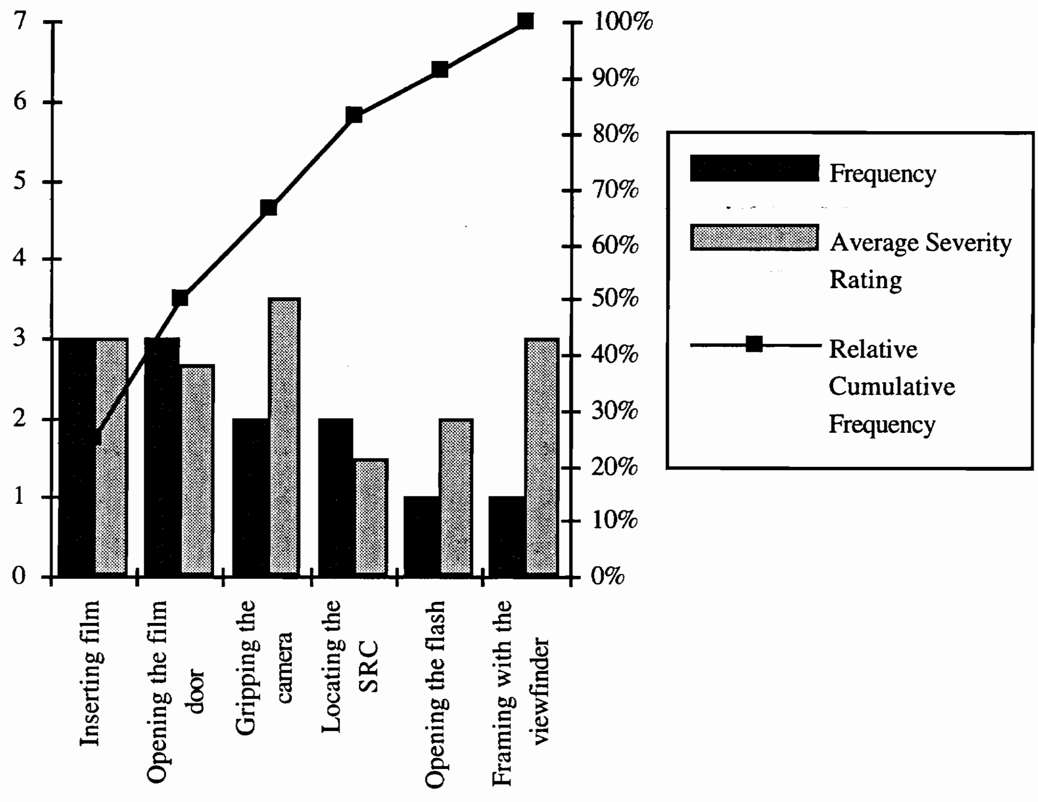

Figure 5. Impact Analysis Graph for Arthritics

Camera Ratings

Although sample sizes in each group were unequal, results of the ratings were analyzed with one-way ANOVAs. Only ratings of the camera ease of use and of the shutter release control ease of use were found significantly different across groups. The summary tables for each of these two variables are presented in Table 6 and Table 7. Newman-Keuls tests indicate that the difference is due to quadriplegics rating the camera and the shutter release control significantly more difficult to use than the other groups as Table 8 and Table 9 show.

Table 6. ANOVA Summary Table for Camera Ease of Use

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Group	3	12.959	4.320	5.521	.0067
Residual	19	14.867	.782		
Total	22	27.826			

Table 7. ANOVA Summary Table for SRC Ease of Use

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Group	3	33.909	11.303	4.410	.0163
Residual	19	48.700	2.563		
Total	22	82.609			

Table 8. Newman-Keuls Test on the Group Effect for Camera Ease of Use

Student-Newman-Keuls
Effect: Group
Significance level: .05

	Count	Mean	N-K
Younger Adults	6	1.333	a
Older Adults	6	1.500	a
Arthritics	5	1.600	a
Quadriplegics	6	3.167	b

Table 9. Newman-Keuls Test on Group Effect for SRC Ease of Use

Student-Newman-Keuls
Effect: Group
Significance level: .05

	Count	Mean	N-K
Younger Adults	6	1.333	a
Older Adults	6	1.333	a
Arthritics	5	1.600	a
Quadriplegics	6	4.167	b

Average ratings on each scale for each group are shown in Table 10. Gripping and stabilizing the camera, although not significant in the previous ANOVA ($p > 0.05$), were rated over 3.00 in average by quadriplegics. Overall ratings of the camera vary between 1.67 (older adults) to 2.83 (younger adults) only. These ratings can be considered as good ratings on a scale of seven, indicating that all groups did like the camera. Subjects' comments show indeed that people appreciate the light weight and the small pocketable size of the camera.

Table 10. Average Ratings of the Camera per Group

Group	Ease of use	Ease of grip	Stability	Film loading	Flash opening	Shutter release control	Overall rating
Younger Adults	1.33	1.33	2.17	2.33	2.00	1.33	2.83
Older Adults	1.50	1.33	1.17	3.33	2.50	1.33	1.67
Quadriplegics	3.17	3.00	3.50	2.67	1.33	4.17	2.75
Arthritics	1.60	1.80	1.80	3.00	1.60	1.60	1.80

Hand Measurements

The dynamometer and the pinch meter used to evaluate grip strengths and pinch strengths were not sensitive enough for the very low strengths of most quadriplegics. Where data could not be collected, a value of zero was given. The pegboard test could not be performed by all quadriplegics either. The task was too difficult for half of them, and was performed usually with both hands by the remaining half. Only one quadriplegic subject performed the peg board test with the left hand. Results of analyses on manual dexterity performances should therefore be accepted with caution.

One-way ANOVAs were conducted on all hand measurements. There is a main Group effect on all variables. The ANOVA summary tables for each hand measurement are presented in Table 11. Results of Newman-Keuls post-hoc tests detailing the main effect are shown in Table 12. For pinch and grip strengths, the averages are always in the same increasing order: quadriplegics, arthritics, older adults, and younger adults. Significant differences exist between quadriplegics and able-bodied subjects on all measurements. Grip strengths of arthritics are also statistically weaker than grip strengths of able-bodied subjects. However, their pinch strengths are similar to the pinch strengths exerted by the group of older adults.

Table 11. ANOVA Summary Tables for Hand Measurements

Grip Right

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Group	3	9044.167	3014.722	9.677	.0004
Residual	19	5919.050	311.529		
Total	22	14963.217			

Grip Left

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Group	3	10363.088	3454.363	13.856	.0001
Residual	19	4736.717	249.301		
Total	22	15099.805			

Pinch Right

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Group	3	841.215	280.405	9.937	.0004
Residual	19	536.127	28.217		
Total	22	1377.342			

Pinch Left

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Group	3	939.920	313.307	13.219	.0001
Residual	19	450.325	23.701		
Total	22	1390.245			

Dexterity Right

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Group	3	5145.954	1715.318	6.463	.0050
Residual	15	3980.783	265.386		
Total	22	1980.704			

Dexterity Left

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Group	3	3276.617	1092.206	34.570	.0001
Residual	12	379.133	31.594		
Total	22	3655.750			

Table 12. Newman-Keuls Post-hoc Tests for Hand Measurements

Grip Right

	Count	Mean	N-K
Quadriplegics	6	12.917	a
Arthritics	5	24.200	a
Older Adults	6	46.667	b
Younger Adults	6	63.417	b

Grip Left

	Count	Mean	N-K
Quadriplegics	6	2.750	a
Arthritics	5	23.700	b
Older Adults	6	45.667	c
Younger Adults	6	57.083	c

Pinch Right

	Count	Mean	N-K
Quadriplegics	6	4.750	a
Arthritics	5	12.650	b
Older Adults	6	16.000	b c
Younger Adults	6	21.042	c

Pinch Left

	Count	Mean	N-K
Quadriplegics	6	2.750	a
Arthritics	5	11.850	b
Older Adults	6	16.000	b c
Younger Adults	6	19.500	c

Dexterity Right

	Count	Mean	N-K
Arthritics	4	23.750	a
Younger Adults	6	28.833	a
Older Adults	5	30.600	a
Quadriplegics	4	68.000	b

Dexterity Left

	Count	Mean	N-K
Arthritics	4	24.500	a
Younger Adults	6	29.667	a
Older Adults	5	34.200	a
Quadriplegics	1	87.000	b

Correlations between pinch strengths and grip strengths were measured for each hand. Correlation is 0.912 for right hand measurements and 0.928 for left hand measurements. Because of the high values of these correlations, it was deemed unnecessary to measure pinch strength when grip strength was measured in the remaining of the study.

Discussion

All data whether coming from critical incidents, camera ratings, subjective comments, or hand measurements, underline the differences between quadriplegics and people without disabilities of the same age. The use of the camera is significantly more difficult for quadriplegics, although they seemed to like the product. As a matter of fact, two subjects even expressed interest in buying the camera.

The critical incident technique should allow identification of the obstacles met by the users of different groups. Table 13 summarizes the problems reported by each group listed by decreasing order of frequency. People without disabilities mainly commented on the difficulty of inserting film in the camera and the absence of a frame in the viewfinder. For older adults, the latches of the film door and the flash should be color coded and enlarged.

Table 13. Summary of Problems Reported by Subjects

Younger Adults	Older Adults	Quadriplegics	Arthritics
Inserting film	Inserting film	Opening the film door	Inserting film
Opening the flash	Finding the film door latch	Pushing the SRC *	Opening the film door
Framing with the viewfinder	Finding the flash latch	Gripping the camera	Gripping the camera
	Knowing flash status	Inserting film	Locating the SRC
Closing the flash	Pushing the SRC	Reaching the SRC *	Opening the flash
Using the viewfinder	Framing with the viewfinder	Opening the flash	Framing with the viewfinder
Locating the SRC	Opening the film door	Finding the film door	

* this critical incident was rated with a severity of seven

Problems in pushing the shutter release control and in gripping the camera were expressed only by arthritics and quadriplegics. Reaching the shutter release control and opening the film door were more frequently problems for these subjects as well. Subjects with disabilities found the film door latch too small, and many complained that it required fingernails to be opened. Videotapes confirm that the action of opening the film door is difficult with weak fingers or hands. However, the major problem for some quadriplegics was the activating force of the shutter release control. They requested that the button be easier to push and be moved to another location, on the side or back of the camera, where they could reach it with their thumb. Subjects from different groups also suggested that the control should be raised.

The camera was hard to hold for some disabled subjects, because it is too smooth and does not offer a grip. This can be easily observed on the videotapes of some subjects and is reflected in the ratings of the camera ease of grip. Subjects without disabilities never reported the grip on the camera as a critical incident, but they made comments about it during the interviews. Subjects from all groups asked for indentations and ridges on the front left and on the back of the camera, similar to the small notch existing on the front right of the model tested.

Although reported as separate problems, pushing and reaching the SRC and gripping the camera are actually part of one action: taking a picture. All problems are closely entangled. Pushing the button when you have a good grip on the camera is easier, since the camera does not slip out of the hand. If the shutter release control is in a location that is easy to reach, then the user can hold the camera more easily. If the button requires less force, the camera will not shake as much in the hand, and the user's grip does not need to be as secure. Therefore, solutions to move the shutter release control, and to make it easier to push, should be searched as well as new ways of offering an improved grip on the camera.

In this experiment, the group of people with arthritis was very heterogeneous. Some subjects did not show any actual hand deformation, sometimes because they were under medication. Others had only very localized arthritis, such as only in the thumb. Comments by different subjects in the group are sometimes contradictory, and it is difficult to rely on their suggestions for the design of alternative cameras. A better homogeneity in the level of disability in this group should be looked for in the remaining of the study.

Summary

Multiple techniques were used in Phase I to collect data on the usability problems of people with manual impairments when using a NSLR camera. When analyzed, results seem to indicate that the main accessibility barriers of the camera occur in the picture taking phase. These barriers can prevent the use of the camera for some quadriplegics. The camera is difficult to grip and the shutter release button difficult to push. In Phase II, the prioritization process of the problems reported by subjects confirms the importance of these two barriers.

PHASE II

The purpose of Phase II is to design alternatives to the camera tested that would eliminate the major barriers for users with hand impairments. Accessibility obstacles were identified during Phase I, and data about their frequency and severity were collected. The first step of Phase II is therefore to select the barriers that need to be removed to significantly improve camera accessibility for users with manual dysfunctions.

Method

Barrier Selection

Criteria were combined to prioritize the usability problems. These criteria are listed in order of decreasing importance.

- "Blocking" vs. "ease of use" problem

  A blocking problem, if not solved, prevents the user from going to the next step of the procedure and from completing the action (e.g., being unable to open the flash of the camera). By opposition, if an "ease of use " problem is not corrected, the user could still complete the action, but with difficulty (e.g., finding it hard to open the film door). Problems given severity ratings of seven (highest rating possible on the scales presented to subjects) are considered as blocking problems and will be given a higher priority.

- Commonalty across groups

  The more groups are concerned by the problem, the better the chances for the selection of the problem . This is particularly true for problems that are met by participants from both groups of people with hand impairments.

- Severity of the problem

  The average severity ratings of each problem will also be used as a criterion.

- Impact of the problem

  Impact Analysis allows designers and engineers to visualize the impact of the modifications they make on a product. In this case, the impact analysis graphs show the percentage of all problems that will be solved with the elimination each problem. It is a way of using frequency of a problem as a criterion for prioritization.

- Frequency of the task

  It is more important to correct problems that occur on more frequently performed tasks. A problem occurring when trying to take a picture will therefore receive a higher priority than one happening when loading or unloading the film.

The problems reported as critical incidents are listed by order of decreasing priority in Table 14. Because of their blocking aspect, and of the high severity ratings they received, the problems of reaching the shutter release control and pushing it received the highest priority. The problem of holding the camera is important because it is a severe problem for arthritics and quadriplegics. It is also important because it makes it more difficult to successfully complete the task of capturing an image. Opening the film door was a frequent problem for both groups of subjects with disabilities. However, it was usually rated with a lower severity than the problems with the SRC and the grip, and occurs less often. Other frequent problems include loading a roll of film, opening the flash, and framing with the viewfinder. But, they were reported mostly by non-disabled subjects and received lower priorities. Finding the film door latch received a relatively severe average rating, but it is a problem specific to the group of older adults. Other problems were too rare or not severe enough to be considered.

Table 14. List of Problems Reported in Decreasing Order of Priority

Pushing the shutter release control
Reaching the shutter release control
Gripping the camera
Opening the film door
Inserting the film
Opening the flash
Finding the film door latch
Framing with the viewfinder

Because of the time frame of this research, only the four first problems in Table 14 could be selected. The following steps of Phase II will narrow down this selection.

Brainstorming Session

Results of Phase I were presented to industrial designers. They were shown videotapes of some subjects with disabilities using the camera, and given facts and data about quadriplegia and arthritis and the type of hand impairments they cause. The presentation was followed by a brainstorming session on how to find alternatives to the current camera, and solve the problems selected. Three industrial designers, one human factors engineer, and the experimenter of this study took part in the brainstorming.

During the discussion with designers, it appeared that any modification to the film loading system or film door system would be very difficult to implement. It was also unclear how much could be done about the shutter release control, since changing it required the participation of a camera engineer and probably modification of the electronics of the camera. Therefore, most of the brainstorming was directed towards improving the grip of the camera.

The outcome of a brainstorming session is by nature a collection of diverse ideas. Many potential redesigns of the camera, or of assistive devices for the camera, were proposed for this study. Cost and time constraints were the decisive criteria used to select possible designs. Indeed, some of the designs proposed required too much research, completion time, or money.

During this brainstorming session, it was also decided that the selected designs should vary in the type of camera redesign, from little modifications on the body of the camera to the addition of an assistive device. A new model of camera to be tested in the remaining of the study was also chosen. The autofocus version of the camera used in Phase I, shown in Figure 6, was selected, because it has a tripod socket, which allows an assistive device to be screwed in the camera. According to the designers, attaching a device to a camera would be difficult without a tripod socket. The dimensions of the autofocus camera are a few millimeters bigger, the shutter release control is completely flush with the body of the camera, however, the flash offers less resistance.

Literature Research

A search was conducted to find what products currently exist to improve gripping abilities of quadriplegics and arthritics. Catalogs of assistive devices were shown to designers. Velcro straps, cup-holders, and hooks for telephones provided inspiration for the new designs. The Good Grips line of cutlery, developed especially for people with arthritis, was also investigated (Viemeister, 1992).

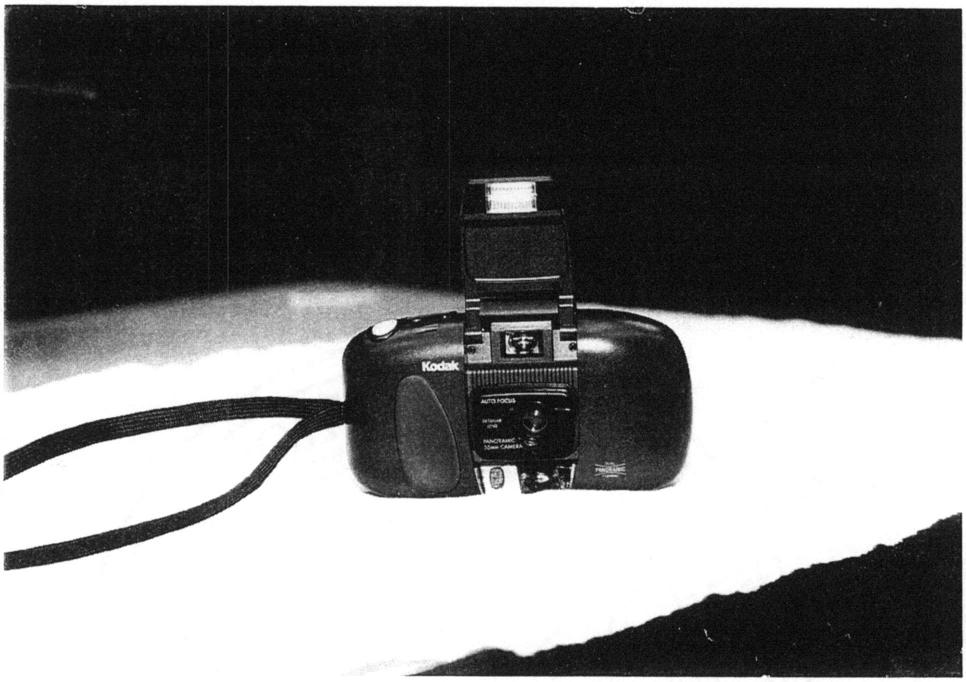

Figure 6. Standard Camera

Expert Consultation

In this phase of the study, experts were consulted rather than potential users. Experts have a general understanding of abilities of arthritics and quadriplegics as well as a knowledge of existing products for people with disabilities that users might not be aware of. The prototypes were brought to a physical therapist, and an occupational therapist for comments and suggestions. Physical therapists help patients in the physical aspects of their rehabilitation, while occupational therapists assess abilities of patients and adapt systems for them. Both experts agreed that some designs should help the users with disabilities, but could also foresee problems with other models. They recommended testing these models for users' reactions.

Results

The result of Phase II is the development of four new camera designs or assistive devices for the camera. Three designs enhance the grip and one design modifies the shutter release control.

Grips

Rubber Pads Camera. The first alternative camera is the one requiring the least modifications of the standard camera. Based on subjects' suggestions, the texture of the surface of the camera was modified where people usually place their fingers on a camera. Rubber pads were added on the front right side where an indentation already exists, on the front left side, and on the left side on the back where many people place their thumbs. In addition, the two pads on the front were made a little thicker to see if gripping a slightly thicker camera is preferred over the standard camera. A picture of this modified camera, called the Rubber Pads Camera, is shown in Figure 7.

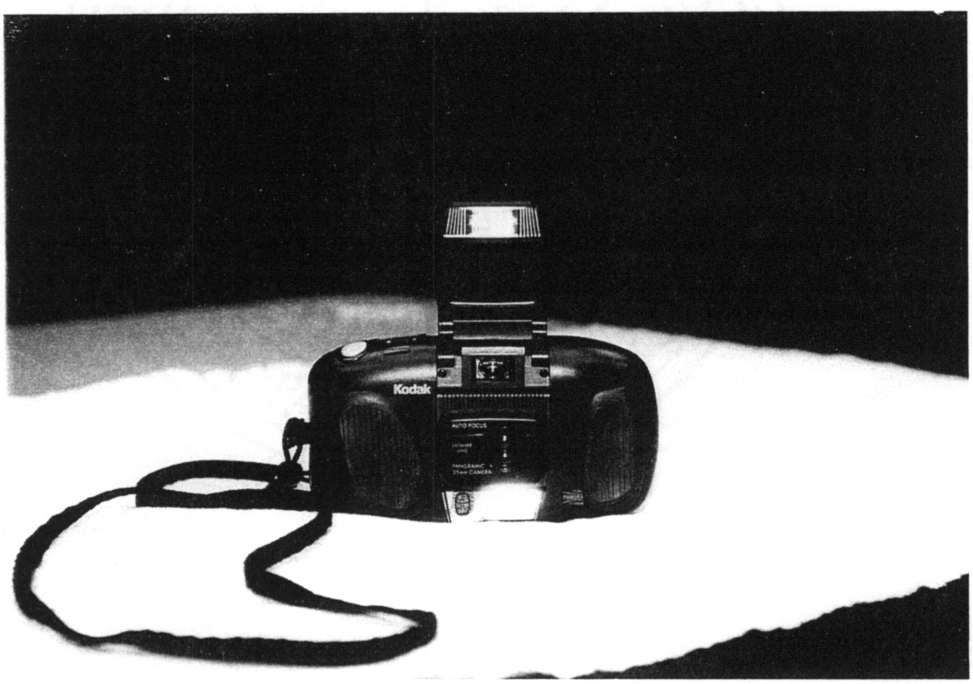

Figure 7. The Rubber Pads Camera

Thumbsleeve Camera. The thumb is usually the strongest finger for quadriplegics. The Thumbsleeve Camera was designed so that users could hold the camera by using only their thumb. An adjustable Velcro sleeve can be placed either on the back left or back right of the camera. The angle at which the sleeve is fixed can be chosen by the user. The user can then slide the thumb in it, and lift the camera without having to wrap the other fingers around the camera too tightly. The prototype is shown in Figure 8. Once the prototype was developed, it was actually discovered that the sleeve could be used with other fingers than the thumb, offering yet another way of gripping the camera that might be easier for some users.

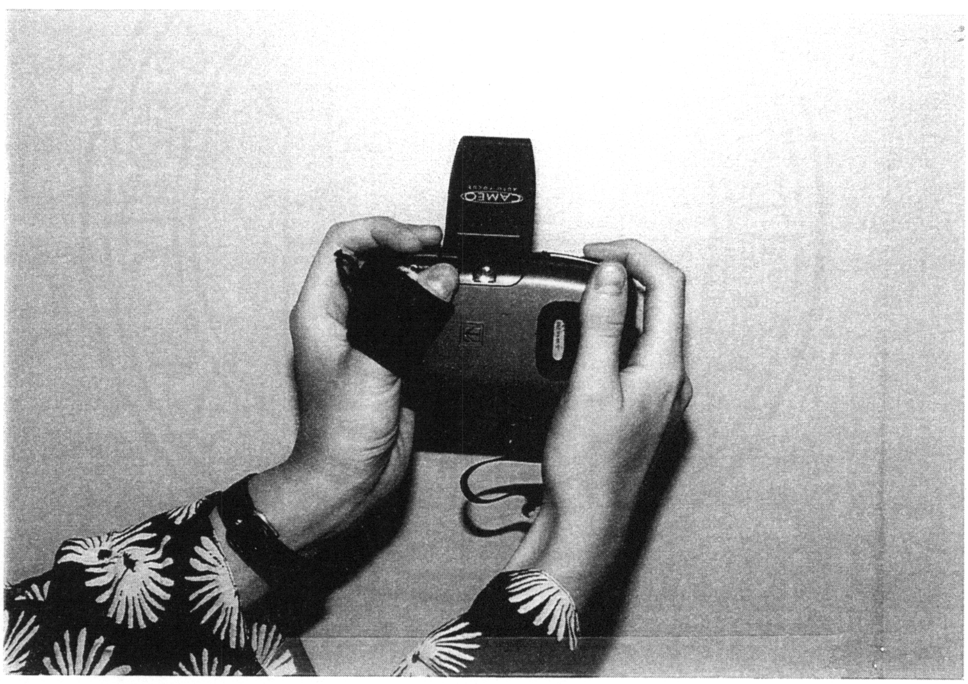

Figure 8. The Thumbsleeve Camera

The Handle. The last design is an assistive device that could be attached on any camera with a tripod socket. The device is made out of a handle, borrowed from a Good Grips knife, and a Velcro strap. A large metal knob allows the device, called the Handle, to be screwed in the tripod socket. The position of the handle, on the left, right, front, or back of the camera, is adjustable. The device is shown in Figure 9.

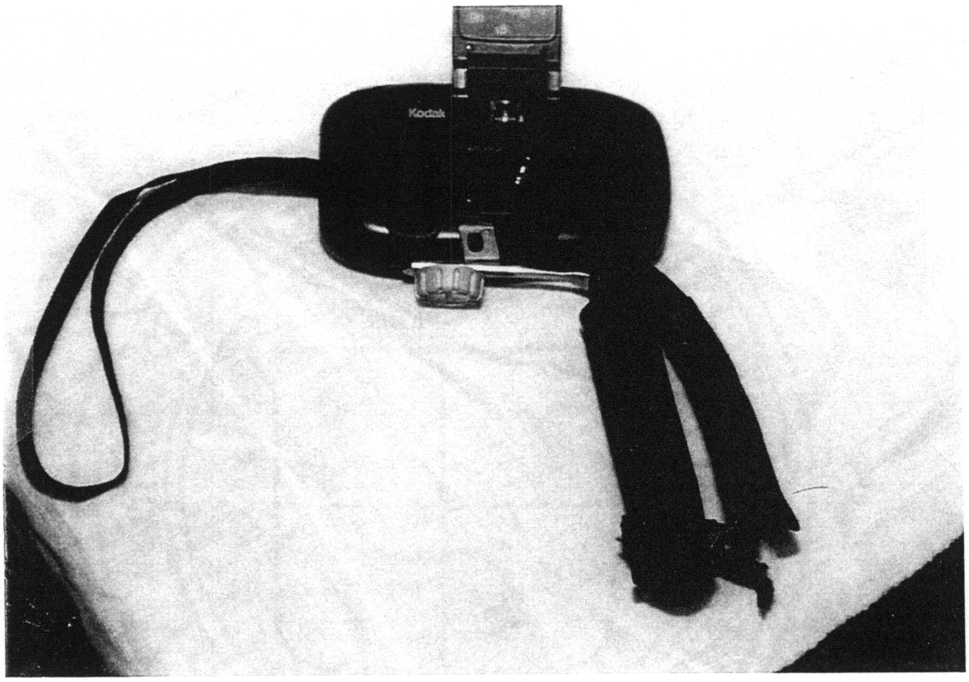

Figure 9. The Handle Camera

Shutter Release Control

One of the cameras was adapted with a remote shutter release control. A small and thick black button was fixed at the end of a short wire (about a foot long). The button used on the remote SRC is easier to trigger than the one on the camera. When pressed, it releases the shutter, exactly like the standard control on the top right of the camera. When an adhesive material is applied on the back of the button, the remote SRC can be placed wherever a user wants on the camera. If the wire is ignored, this simulates a camera with a shutter release control in a different place than the standard top right location. This prototype offers flexibility to the user, and should be a useful tool to eliminate the "reaching the SRC" barrier. A camera with this device is shown in Figure 10.

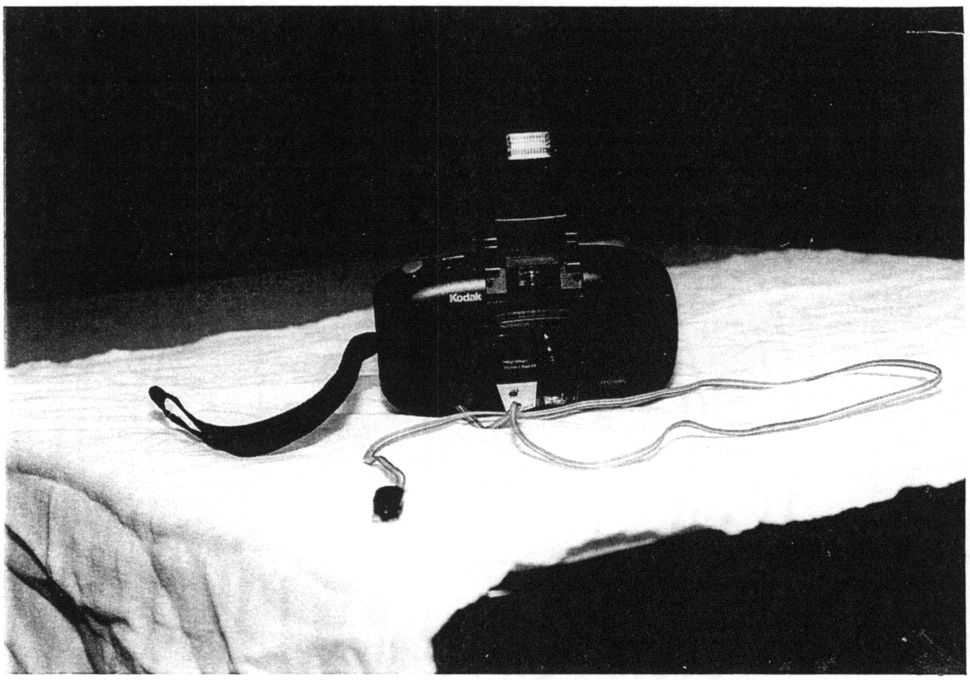

Figure 10. The Remote SRC Camera

Summary

Four new camera models were designed and developed in Phase II, either by modifying the camera or by adding a device to it. All alternatives were designed to eliminate at least one of the barriers selected in an earlier step of the study. These camera prototypes were developed so that pictures could be taken with them, and so that they could be compared in the designed experiment of Phase III.

PHASE III

The third phase of the study consists of a designed experiment, to evaluate the selected prototypes and confirm the elimination of some accessibility barriers.

Method

Four camera modifications were developed in Phase II, either to improve the grip on the camera, or to improve the shutter release control. This can be seen as improving the camera independently along two different dimensions. Studying both grip and shutter release control improvements is also needed. In other words: does it lead to an optimal camera, or does only one dimension need to be modified? Since the handle was developed as an assistive device, it can be attached to the Remote SRC Camera to form a fifth alternative design. A picture of this model can be seen in Figure 11. Since comparison of the alternative models with the standard one is necessary to verify the elimination of barriers, six camera models were tested by the subjects of this experiment.

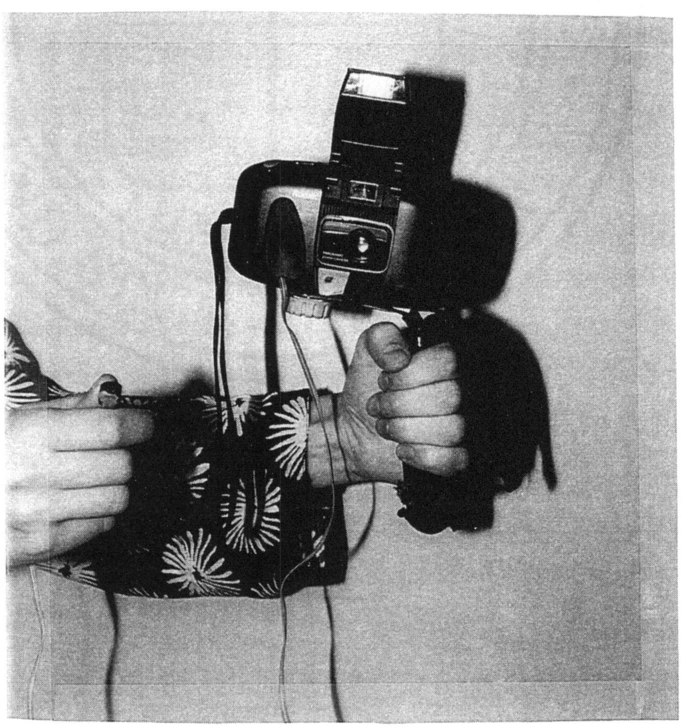

Figure 11. The Remote SRC and Handle Camera

Research Design

The independent variables for the experiment are the type of grip, the type of SRC, and the subject group. The factors are detailed in the following list.

- The Type of Grip (four levels): Standard, Rubber Pads, Thumbsleeve, and Handle
- The Type of Shutter Release Control (two levels): Standard and Remote
- The subject's Group (four levels): Younger Adults, Older Adults, Quadriplegics, and Arthritics

Although each subject tried all six models of the camera, two designs are necessary to analyze correctly the data collected in the study. The first analysis deals with the type of grip on the camera and compares in a 4x4 mixed factorial design all cameras that share the same standard shutter release control: the Standard, the Rubber Pads, the Thumbsleeve, and the Handle models. The second analysis concerns the Standard, the Handle, the Remote SRC, and the Remote SRC and Handle cameras. Only two levels of the Type of Grip factor are used (the standard grip and the handle grip) in this 4x2x2 mixed factorial design.

Dependent variables consist of performance measurements and subjective ratings. Studies have shown that the way users hold a camera is related to camera shake (Eisen 1990). If the shutter release control has a high operating force, the camera should tilt in the user's hand and framing tilt should appear on their pictures. Therefore, framing tilt and camera shake were collected on subjects' pictures. In addition, the presence of a finger or strap obstructing the lens was recorded.

Subjective ratings of the ease of use, the ease of grip, and the stability of the different cameras and subjective ratings of the ease of push and ease of reach of the shutter release controls were the other dependent variables. These ratings were done on seven-point Likert scales that can be found in Appendix F. Subjects were also asked to place the cameras on a 20 point scale according to their relative ease of use.

Subjects

Eight subjects in each group were tested. Participants were recruited in the Rochester, NY area. Subjects with arthritis were recruited with the help of the Arthritis Foundation Genesee Chapter. This association also provided a room for the testing. Other subjects were tested in Eastman Kodak Company facilities. Able-bodied subjects were selected so that they took less than 10 rolls of film per year and were not involved in camera design. They were recruited at universities and senior centers throughout the city.

Procedure

Subjects were given a consent form (close to the one in Appendix A) and a description of the procedure of the experiment, as shown in Appendix G. A measurement of their hand grip strength was then taken. Subjects were asked to take three pictures of a full scale cardboard cutout of a person with each of the six camera models. Camera presentation orders were randomized. The subjects were instructed that the first picture was only a training picture, while the next two pictures would be analyzed. For the two models with the remote SRC, they were invited to place the SRC where it was most convenient for them on the camera or to use it in their hand. They were also invited to adjust the handle and the thumbsleeve to their own needs. Completion of the task, the type of grip used, location selected for the SRC, and eventual false shots were noted by the observer.

Once the subjects had taken the required pictures with each of the camera models, they were given a questionnaire in which they were asked to rate the cameras. Other questions were asked in a short interview to obtain more detailed subjective opinions on the use of each camera or device. This questionnaire can be found in Appendix F.

Results

The results of the experiment were divided into performance measurements and subjective opinions. Two different analyses of the data for each dependent variable were required given the nature of the prototypes used in the experiment. The first analysis is a Grip Analysis, involving only the cameras with the standard shutter release control: the Standard, the Rubber Pads, the Thumbsleeve, and the Handle models. The second analysis is a Grip and SRC Analysis, comparing the Standard, the Handle, the Remote SRC, and the Remote SRC and Handle models.

Performance Measurements

Three types of performance measurements were collected: framing tilt, camera shake, and lens obstruction. Performance measurements of framing tilt and camera shake were done on two four-point ordinal scales. Pictures were compared to standards developed from consumers and were given the following ratings depending on the importance of the problem:

- 4 if the problem is not present
- 3 if the problem is detectable
- 2 if the picture is objectionable
- 1 if the picture is not worth keeping

A value of zero was given in the few cases when no picture was available, when subjects were unable to use one of the cameras in the study. Each subject was invited to take three pictures with each camera. The average of the ratings for the two last pictures was used in the data analysis, since the first picture was for training. A reliability test of the observer's picture ratings was conducted on 32 pictures randomly selected. Correlation between first and second ratings was 1.00 for Camera Shake and 0.72 for Framing Tilt.

Results were analyzed with non-parametric tests, given the ordinal nature of the scales used. Friedman two-way analyses of variance by ranks were conducted to detect overall significances across the 16 conditions in each design . Wilcoxon-Mann-Whitney tests (Wx) were performed on pairs of conditions on independent samples (same camera model but different groups), and Wilcoxon signed ranks tests (T+) were performed on pairs of conditions with related samples (same group but different camera models).

Presence or absence of fingers or straps on the prints was noted for available pictures. The data collected is of nominal type, and should be analyzed with a non-parametric test. However, the sample size of this experiment and the frequency of cases when fingers or straps are obstructing the lens are both too small for any such test to be valid. Therefore, no analysis and only data will be reported for this dependent variable.

<u>Framing Tilt</u>. The Friedman two-way analysis of variance by ranks summary table for the Grip Analysis is presented in Table 15. There is an overall difference across the 16 conditions. Table 16 presents the significant results of the Wilcoxon-Mann-Whitney tests performed on pairs of conditions involving the same camera. The average rank is given in parenthesis for each condition. Quadriplegics performed worse than the Older Adults and the Younger Adults with all cameras but the Thumbsleeve camera. However, their results are different from the ones obtained by the Arthritics only for the Standard Camera. Arthritics performed as well as able-bodied subjects, except when using the Rubber Pads camera. Comparisons of matched pairs revealed no significant differences at the 0.05 level between cameras within each group. Therefore, no results from Wilcoxon signed rank tests are presented.

The results of the Friedman two-way analysis of variance for the Grip and SRC Analysis, presented in Table 17, show a significant overall effect. Wilcoxon-Mann-Whitney tests indicate that this effect is due again to Quadriplegics performing significantly worse than the three other groups on the standard and handle camera. The remote shutter release control reduces the framing tilt significantly. Its presence on the camera cancels framing tilt differences between groups. Results are shown in Table 18. However, no differences are found at the 0.05 level across cameras within each group when applying Wilcoxon signed rank tests.

Table 15. Summary Table for the Grip Analysis of Framing Tilt

Degrees of Freedom	15	
Number of Conditions	16	
Number of Cases	8	
Chir-Square	39.549	(p = .0005)
Chi square corrected for ties	**54.564**	**(p = .0001)**
Number of tied groups	22	

Table 16. Wilcoxon-Mann-Whitney Tests on Framing Tilt (Grip Analysis)

Camera	Group	Mean Rank	Group	Mean Rank	Wx	p
Standard:	Quadriplegics	(5.31)	Younger Adults	(11.69)	42.5	.0070
	Quadriplegics	(5.00)	Older Adults	(12.00)	40	.0018
	Quadriplegics	(5.69)	Arthritics	(11.31)	45.5	.0206
Rubber Pads:	Quadriplegics	(5.56)	Younger Adults	(11.44)	44.5	.0148
	Quadriplegics	(5.00)	Older Adults	(12.00)	40	.0018
	Arthritics	(6.00)	Older Adults	(11.00)	48	.0380
Thumbsleeve:	No significant differences					
Handle:	Quadriplegics	(5.50)	Younger Adults	(11.50)	44	.0104
	Quadriplegics	(5.62)	Older Adults	(11.38)	45	.0148

Table 17. Summary Table for the Grip and SRC Analysis of Framing Tilt

Degrees of Freedom	15	
Number of Conditions	16	
Number of Cases	8	
Chir-Square	25.062	(p = .0491)
Chi square corrected for ties	**36.02**	**(p = .0018)**
Number of tied groups	20	

Table 18. Wilcoxon-Mann-Whitney Tests on Framing Tilt (Grip and SRC Analysis)

Camera	Group	Mean Rank	Group	Mean Rank	Wx	p
Standard:	Quadriplegics	(5.31)	Younger Adults	(11.69)	42.5	.0070
	Quadriplegics	(5.00)	Older Adults	(12.00)	40	.0018
	Quadriplegics	(5.69)	Arthritics	(11.31)	45.5	.0206
Handle:	Quadriplegics	(5.50)	Younger Adults	(11.50)	44	.0104
	Quadriplegics	(5.62)	Older Adults	(11.38)	45	.0148
Remote SRC:	No significant differences					
Remote SRC and Handle:	No significant differences					

Camera Shake. The summary table of the Grip Analysis on Camera Shake, presented in Table 19, shows a overall effect. Wilcoxon-Mann Whitney tests show that the effect is due to significantly lower performances by Quadriplegics on all four cameras. Results are presented in Table 20. However, a Wilcoxon signed rank test indicate that the pictures quadriplegics took with the Handle camera show significantly less camera shake than the pictures taken with the standard camera. This result is shown in Table 21. Differences in camera shake due to camera type do not exist for the other groups.

Table 19. Summary Table of the Grip Analysis on Camera Shake

Degrees of Freedom	15	
Number of Conditions	16	
Number of Cases	8	
Chir-Square	47.294	(p = .0001)
Chi square corrected for ties	**85.22**	**(p = .0001)**
Number of tied groups	15	

Table 20. Wilcoxon-Mann-Whitney Tests on Camera Shake (Grip Analysis)

Camera	Group	Mean Rank	Group	Mean Rank	Wx	p
Standard:	Quadriplegics	(4.50)	Younger Adults	(12.50)	36	.0002
	Quadriplegics	(4.50)	Older Adults	(12.50)	36	.0002
	Quadriplegics	(4.50)	Arthritics	(12.50)	36	.0002
Rubber Pads:	Quadriplegics	(5.75)	Younger Adults	(11.25)	46	.0206
	Quadriplegics	(5.25)	Older Adults	(11.75)	42	.0046
	Quadriplegics	(5.25)	Arthritics	(11.75)	42	.0046
Thumbsleeve:	Quadriplegics	(5.87)	Younger Adults	(11.13)	47	.0282
	Quadriplegics	(5.50)	Older Adults	(11.50)	44	.0104
	Quadriplegics	(5.50)	Arthritics	(11.50)	44	.0104
Handle:	Quadriplegics	(6.00)	Younger Adults	(11.00)	48	.0380
	Quadriplegics	(6.00)	Older Adults	(11.00)	48	.0380
	Quadriplegics	(6.00)	Arthritics	(11.00)	48	.0380

Table 21. Wilcoxon Signed Rank Tests on Camera Shake (Grip Analysis)

			T+	p
Quadriplegics:	Handle vs.	Standard	26.5	.0468

As can be seen in the Summary Table presented in Table 22, there is still an overall effect in the Grip and SRC Analysis. Results from Wilcoxon-Mann-Whitney tests, shown in Table 23, confirm results of the Framing Tilt analysis: although Quadriplegics performed worse than the subjects from all three other groups with the Standard and Handle models, there are no more differences in Camera Shake between groups when the remote SRC is added to the cameras. The remote SRC brought the performance of Quadriplegics up to the level of other subjects. Results of Wilcoxon signed rank tests, shown in Table 24, indicate indeed that the results of quadriplegics when using the cameras with the remote SRC are significantly different from their results with the Standard Camera. The difference between their performances with the Standard camera and the Handle one is the same as in the previous analysis.

Table 22. Summary Table of the Grip and SRC Analysis on Camera Shake

Degrees of freedom	15	
Number of Conditions	16	
Number of Cases	8	
Chir-Square	31.798	(p = .0069)
Chi square corrected for ties	**67.862**	**(p = .0001)**
Number of tied groups	14	

Table 23. Wilcoxon-Mann-Whitney Tests on Camera Shake (Grip and SRC Analysis)

Camera	Group	Mean Rank	Group	Mean Rank	Wx	p
Standard:	Quadriplegics	(4.50)	Younger Adults	(12.50)	36	.0002
	Quadriplegics	(4.50)	Older Adults	(12.50)	36	.0002
	Quadriplegics	(4.50)	Arthritics	(12.50)	36	.0002
Handle:	Quadriplegics	(6.00)	Younger Adults	(11.00)	48	.0380
	Quadriplegics	(6.00)	Older Adults	(11.00)	48	.0380
	Quadriplegics	(6.00)	Arthritics	(11.00)	48	.0380
Remote SRC:	No significant differences					
Remote SRC and Handle:	No significant differences					

Table 24. Wilcoxon Signed Rank Tests on Camera Shake (Grip and SRC Analysis)

			T+	p
Quadriplegics:	Standard vs.	Handle	26.5	.0468
		Remote SRC	28	.0156
		Remote SRC and Handle	28	.0156

Finger on Lens. Table 25 presents the frequency of pictures showing fingers or straps per Group and per Camera (out of 16 pictures for most of the cells). No test could be applied to these data which are non-dichotomous nominal values, with a small sample size, and some small frequencies. It can be noted that obstruction of the lens is more often a problem for people with disabilities than other groups.

Table 25. Lens Obstruction Frequencies

	Standard	Rubber Pads	Thumbsleeve	Handle	Remote SRC	Remote SRC and Handle
Younger Adults	0	0	2	0	0	0
Older Adults	0	0	0	0	0	0
Quadriplegics	4 (out of 10)	6 (out of 10)	0 (out of 10)	4 (out of 14)	3	4
Arthritics	4	2	6	0	0	2

16 pictures per cell where not indicated

Subjective Opinions

Subjective Opinions were collected with the questionnaire and the short interview shown in Appendix F. Subjects had to rate each camera on five scales: Shutter Release Control Ease of Reach, Shutter Release Control Ease of Push, Camera Ease of Grip, Camera Stability, and Camera Ease of Use. These subjective ratings were recorded on seven point Likert scales. Subjects were also asked to place the cameras according to their ease of use on a 20-point scale. In doing that, they were asked to respect the relative differences in ease of use between cameras.

Results from subjective opinions were analyzed with two ANOVAs conducted on each dependent variable. In the Grip Analysis, Greenhouse-Geisser (G-G) and Huynh and Feldt (H-F) corrections were calculated to compensate for heterogeneity of covariance. No correction is necessary in the Grip and SRC Analysis since the within subject factors possess only two levels each. Newman-Keuls (N-K) post-hoc tests were also conducted on significant effects. Results of Newman-Keuls post-hoc tests conducted on significant interactions are described in the text. The corresponding tables are shown in Appendix H.

Shutter Release Control Ease of Push. The only significant effect on shutter release control ease of push in the Grip Analysis is the Group main effect. The ANOVA summary table for this study is presented in Table 26. Table 27 shows the results of a Newman-Keuls post-hoc test on the Group effect. Results show that Quadriplegics find the shutter release control significantly harder to push than non-disabled people and Arthritics. There is no Grip main effect, which is not surprising, all cameras in this study sharing the same standard shutter release control.

Table 26. ANOVA Summary Table on SRC Ease of Push (Grip Analysis)

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	G-G	H-F
Group	3	334.187	111.396	10.154	.0001		
Subject(Group)	28	307.188	10.971				
Grip	3	2.813	.938	2.598	.0576	.0786	.0669
Grip * Group	9	2.375	.264	.731	.6791	.6361	.6600
Grip * Subject(Group)	84	30.313	.361				
Total	127	676.876					

Epsilon Factors

G-G Epsilon	H-F Epsilon
.720	.865

Table 27. Group Effect on SRC Ease of Push (Grip Analysis)

Student-Newman-Keuls
Effect: Group
Significance level: .05

	Count	Mean	Std. Dev.	N-K
Older Adults	32	1.969	1.576	a
Younger Adults	32	2.750	1.951	a
Arthritics	32	3.406	1.898	a
Quadriplegics	32	6.250	1.078	b

All main effects are significant in the Grip and SRC Analysis. The smmary table of the ANOVA is presented in Table 28. In this analysis, not only are the results from the Quadriplegics different from all other results as usual, but results from Arthritics and from Older Adults subjects are also significantly different from each other. When compared with non-disabled people of the same age, Quadriplegics and Arthritics rated the shutter release controls significantly harder to push. These results are shown in Table 29. The remote shutter release control is rated much easier to push than the standard one. Mean rating is 1.42 for the remote button and 3.62 for the standard one. The handle also significantly improves the ease of pressing the shutter release control. Mean ratings goes from 2.72 without the handle to 2.33 with the handle. There is also a significant Group x Type of SRC interaction effect. Figure 12, where the interaction is plotted shows how all groups preferred the remote SRC. Newman-Keuls post-hoc tests on all conditions of the interaction indicate that there is a difference between types of shutter release control for

Quadriplegics and Arthritics. Quadriplegics rated the standard SRC more severely than all other groups. Arthritics also rated the standard SRC harder to push than Older Adults. The remote SRC is beneficial to both groups of disabled subjects, since there are no more differences in ratings across groups for this type of shutter release control.

Table 28. ANOVA Summary Table for SRC Ease of Push

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Group	3	90.086	30.029	10.698	.0001
Subject(Group)	28	78.594	2.807		
SRC Type	1	155.320	155.320	64.221	.0001
SRC Type * Group	3	73.711	24.570	10.159	.0001
SRC Type * Subject(Group)	28	67.719	2.419		
Grip	1	4.883	4.883	4.845	.0361
Grip * Group	3	.648	.216	.214	.8855
Grip * Subject(Group)	28	28.219	1.008		
SRC Type * Grip	1	.070	.070	.066	.7992
SRC Type * Grip * Group	3	.836	.279	.261	.8526
SRC Type * Grip * Subject(Group)	28	29.844	1.066		
Total	127	529.930			

Table 29. Group Effect on SRC Ease of Push (Grip and SRC Analysis)

Student-Newman-Keuls
Effect: Group
Significance level: .05

	Count	Mean	Std. Dev.	N-K		
Younger Adults	32	1.531	1.135	a		
Older Adults	32	2.125	1.718	a	b	
Arthritics	32	2.625	1.773		b	
Quadriplegics	32	3.812	2.608			c

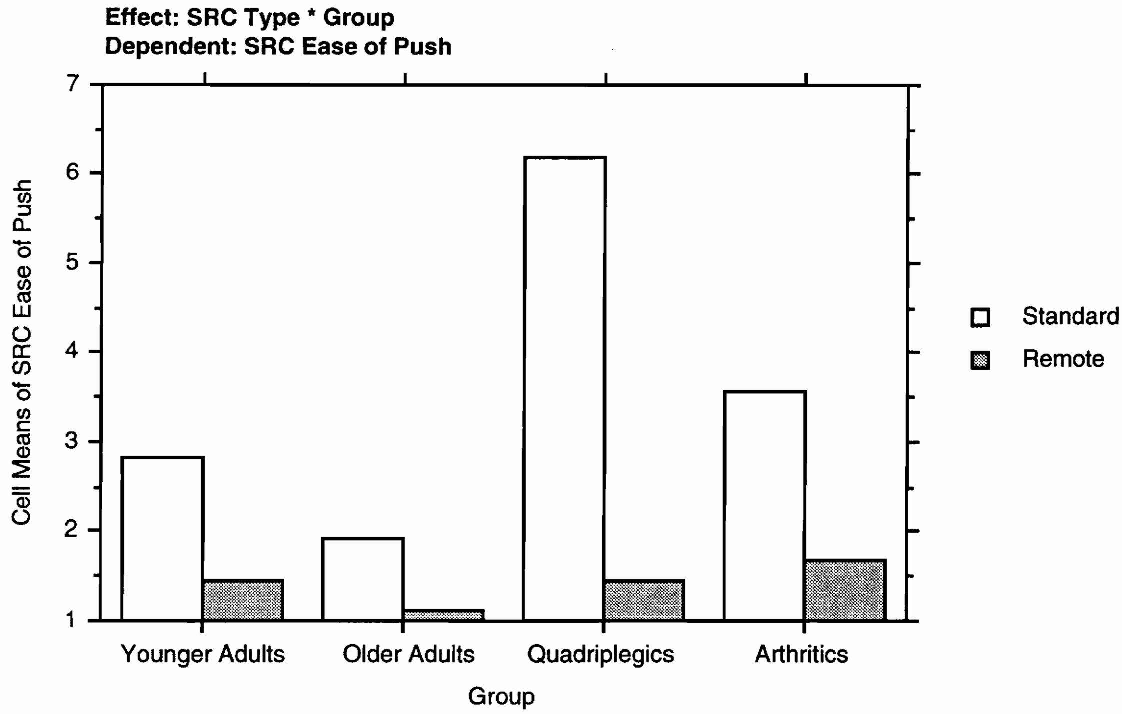

Figure 12. Group x Type of SRC Interaction for SRC Ease of Push

Shutter Release Control Ease of Reach. The differences of grip among cameras does not significantly affect the ease of reach of the shutter release control on these cameras. The ANOVA Summary Table for the Grip and SRC Analysis, presented in Table 30, shows that only the Type of SRC has a significant effect on the shutter release control ease of reach. All groups rated the remote SRC as easier to reach (mean rating is 1.30 for cameras with the remote SRC and 2.95 for other cameras). This result makes sense, since the subjects were invited to place the remote SRC where it was the most convenient for them.

Table 30. ANOVA Summary Table for SRC Ease of Reach (Grip and SRC Analysis)

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Group	3	6.062	2.021	.451	.7185
Subject(Group)	28	125.438	4.480		
SRC Type	1	87.781	87.781	24.320	.0001
SRC Type * Group	3	10.656	3.552	.984	.4144
SRC Type * Subject(Group)	28	101.063	3.609		
Grip	1	.500	.500	2.309	.1398
Grip * Group	3	.937	.312	1.443	.2513
Grip * Subject(Group)	28	6.062	.217		
SRC Type * Grip	1	.031	.031	.275	.6044
SRC Type * Grip * Group	3	.281	.094	.824	.4920
SRC Type * Grip * Subject(Group)	28	3.188	.114		
Total	127	341.999			

Camera Stability. Table 31 presents the results of the ANOVA on Camera Stability for the Grip Analysis. Two effects are significant: the Group main effect and the Grip main effect . Newman-Keuls post-hoc tests on the Group effect (results are in Table 32) show that Quadriplegics rate the stability of the cameras significantly more severely than the other groups. Newman-Keuls post-hoc tests on the Grip main effect (results are in Table 33) indicate that the Handle camera was rated significantly easier to stabilize than the Standard and the Thumbsleeve cameras.

Table 31. ANOVA Summary Table for Camera Stability (Grip Analysis)

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	G-G	H-F
Group	3	93.062	31.021	7.037	.0011		
Subject(Group)	28	123.438	4.408				
Grip	3	29.625	9.875	5.231	.0023	.0094	.0060
Grip * Group	9	26.813	2.979	1.578	.1350	.1747	.1606
Grip * Subject(Group)	84	158.563	1.888				
Total	127	431.501					

Epsilon Factors

G-G Epsilon	H-F Epsilon
.633	.751

Table 32. Group Effect on Camera Stability (Grip Analysis)

Student-Newman-Keuls
Effect: Group
Significance level: .05

	Count	Mean	Std. Dev.	N - K	
Older Adults	32	2.562	1.645	a	
Younger Adults	32	2.719	1.442	a	
Arthritics	32	2.812	1.822	a	
Quadriplegics	32	4.656	1.677		b

Table 33. Grip Effect on Camera Stability (Grip Analysis)

Means Table
Effect: Grip
Dependent: Stability

	Mean	Std. Dev.	N-K	
Thumbsleeve	3.656	1.860	a	
Standard	3.594	1.932	a	
Rubber Pads	3.031	1.823	a	b
Handle	2.469	1.565		b

The ANOVA Summary Table for the Grip and SRC Analysis on Camera Stability is presented in Table 34. All main effects are significant, as well as the Type of SRC x Group interaction. The Group main effect is due to a significant difference between the ratings of older adults and of quadriplegics, as can be seen in Table 35. There are no significant differences between the results of people with disabilities and of people without disabilities of the same age in this study. There is a Grip main effect. Subjects find the handle helpful to stabilize the camera, rating cameras without the handle with a 3.30 average, and the cameras with the handle with a 2.31 average. The remote shutter release control also improves significantly the stability of the cameras. Newman-Keuls post-hoc tests show that Quadriplegics rated the cameras with the standard button significantly harder to stabilize (with an average of 4.19) than the cameras with the remote button (rated with an average of 2.81). Their ratings of the standard button are also significantly more severe than the ratings given by other groups. On the other hand, Arthritics find the cameras with the remote SRC harder to stabilize than Older Adults. This can be visualized in Figure 13, representing the Group x Type of SRC interaction.

Table 34. ANOVA Summary Table for Camera Stability (Grip and SRC Analysis)

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Group	3	29.023	9.674	3.212	.0380
Subject(Group)	28	84.344	3.012		
SRC Type	1	6.570	6.570	8.933	.0058
SRC Type * Group	3	11.086	3.695	5.024	.0065
SRC Type * Subject(Group)	28	20.594	.735		
Grip	1	31.008	31.008	6.015	.0207
Grip * Group	3	29.898	9.966	1.933	.1471
Grip * Subject(Group)	28	144.344	5.155		
SRC Type * Grip	1	.633	.633	1.280	.2675
SRC Type * Grip * Group	3	.773	.258	.521	.6710
SRC Type * Grip * Subject(Group)	28	13.844	.494		
Total	127	372.047			

Table 35. Group Effect on Camera Stability (Grip and SRC Analysis)

Student-Newman-Keuls
Effect: Group
Significance level: .05

	Mean	Std. Dev.	N-K
Older Adults	2.156	1.298	a
Younger Adults	2.750	1.545	a b
Arthritics	2.812	1.786	a b
Quadriplegics	3.500	1.951	b

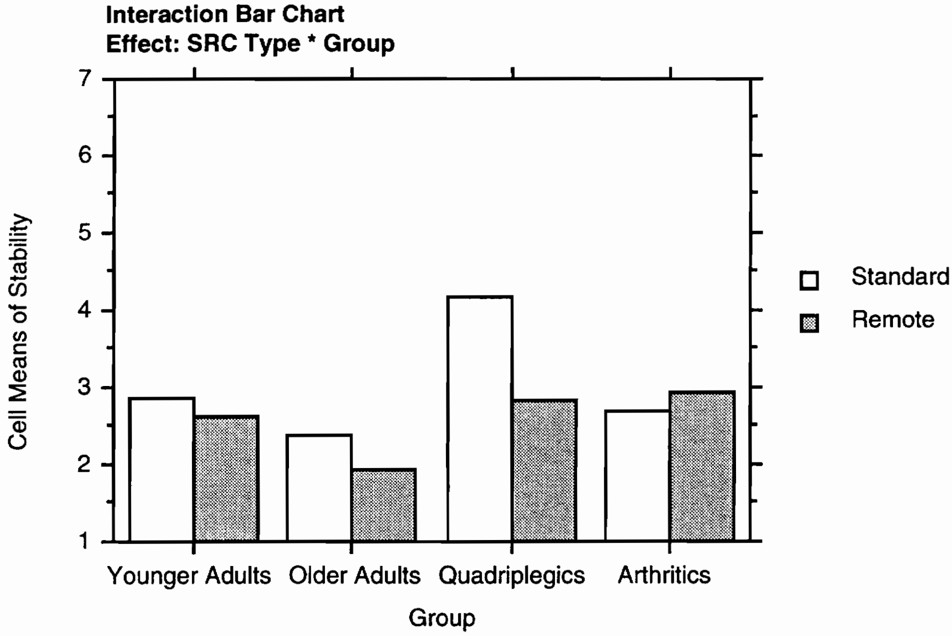

Figure 13. Group x Type of SRC Interaction on Camera Stability

Camera Ease of Grip. The results of the ANOVA of Camera Ease of Grip for the Grip Analysis are presented in Table 36. A Newman-Keuls test on the Group main effect indicates that results from Quadriplegics are once again significantly different from the results of the other groups. Mean ratings are shown in Table 37. This confirms that quadriplegics have more problems gripping the cameras. There is also a significant Grip main effect. Mean Ease of Grip per camera and results of post-hoc tests are listed in Table 38. The Thumbsleeve and the Standard cameras were rated significantly harder to grip than the Rubber Pads and the Handle cameras. The Grip x Group interaction is significant as well and is presented graphically in Figure 14. Differences exist between the ratings of Quadriplegics and other groups for the Standard and the Rubber Pads models, but all groups rated the Thumbsleeve and the Handle models similarly. The handle has a beneficial effect for quadriplegics, who rated the Handle Camera easier to grip than the three others. They also rated the Standard camera harder to grip than the other models.

Table 36. ANOVA Summary Table for Ease of Grip (Grip Analysis)

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	G-G	H-F
Group	3	86.688	28.896	9.653	.0002		
Subject(Group)	28	83.812	2.993				
Grip	3	55.125	18.375	9.246	.0001	.0001	.0001
Grip * Group	9	56.938	6.326	3.183	.0023	.0045	.0023
Grip * Subject(Group)	84	166.938	1.987				
Total	127	449.501					

Epsilon Factors

G-G Epsilon	H-F Epsilon
.839	1.028

NOTE: Probabilities are not corrected for values of epsilon greater than 1.

Table 37. Group Effect on Ease of Grip (Grip Analysis)

Student-Newman-Keuls
Effect: Group
Significance level: .05

	Count	Mean	Std. Dev.	N-K
Older Adults	32	2.500	1.414	a
Arthritics	32	2.812	2.023	a
Younger Adults	32	2.844	1.483	a
Quadriplegics	32	4.594	1.847	b

Table 38. Grip Effect on Ease of Grip (Grip Analysis)

Means Table
Effect: Grip
Dependent: Ease of Grip

	Count	Mean	Std. Dev.	N-K
Thumbsleeve	32	4.094	1.729	a
Standard	32	3.531	2.032	a
Rubber Pads	32	2.594	1.811	b
Handle	32	2.531	1.524	b

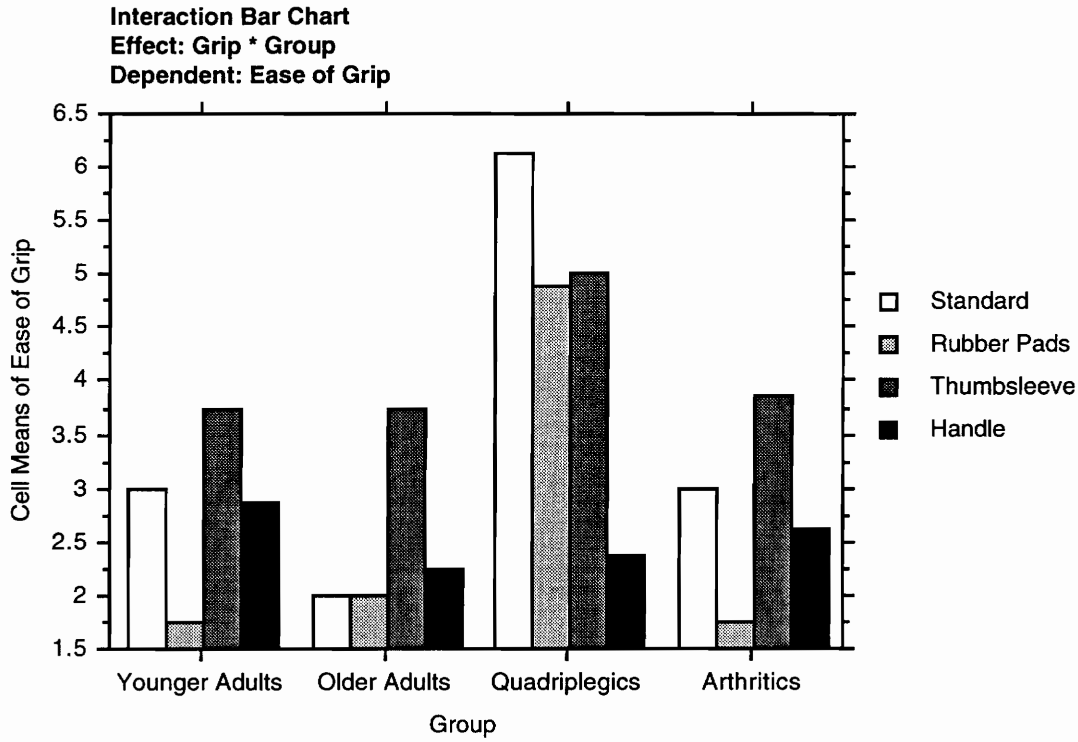

Figure 14. Group x Grip Interaction for Ease of Grip

Table 39 is the ANOVA Summary Table for the Grip and SRC Analysis on Ease of Grip. There is again a Group main effect. A Newman-Keuls post-hoc test shows that the only significant difference is between Older Adults and Quadriplegics, as shown in Table 40. These results are similar to the ones obtained for Camera Stability. Confirming the results of the Grip Analysis, the Type of Grip is also a significant main effect. The handle improves the grip on the camera. Mean ease of grip is 3.33 for the two cameras without the handle, and 2.22 for the two cameras with the handle. The Type of SRC also affects the grip on the camera. The cameras with the standard SRC are rated at 3.03 in average, while the two other ones have an average rating of 2.52. Significant differences are found for the Group x Type of Grip interaction and the Group x Type of SRC as well. Interactions are plotted in Figures 15 and 16 respectively. Post-hoc tests show that, in both cases, the interaction effect is due to Quadriplegics rating the cameras without the handle or without the remote SRC as significantly harder to grip than the other groups. There are also differences between the ratings Quadriplegics gave to cameras without the handle and with the handle - respective means are 5.25 and 1.875 - and between the ratings they gave to cameras without the remote SRC and with the remote SRC - respective means are 4.25 and 2.875.

Table 39. ANOVA Summary Table for Ease of Grip (Grip and SRC Analysis)

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Group	3	36.461	12.154	4.164	.0147
Subject(Group)	28	81.719	2.919		
SRC Type	1	8.508	8.508	9.939	.0038
SRC Type * Group	3	11.273	3.758	4.390	.0118
SRC Type * Subject(Group)	28	23.969	.856		
Grip	1	39.383	39.383	9.740	.0042
Grip * Group	3	55.148	18.383	4.546	.0102
Grip * Subject(Group)	28	113.219	4.044		
SRC Type * Grip	1	.383	.383	.935	.3419
SRC Type * Grip * Group	3	2.898	.966	2.359	.0930
SRC Type * Grip * Subject(Group)	28	11.469	.410		
Total	127	384.430			

Table 40. Group Effect on Ease of Grip (Grip and SRC Analysis)

Student-Newman-Keuls
Effect: Group
Significance level: .05

	Count	Mean	Std. Dev.	N-K
Older Adults	32	2.094	.963	a
Younger Adults	32	2.562	1.343	a b
Arthritics	32	2.875	1.963	a b
Quadriplegics	32	3.562	2.154	b

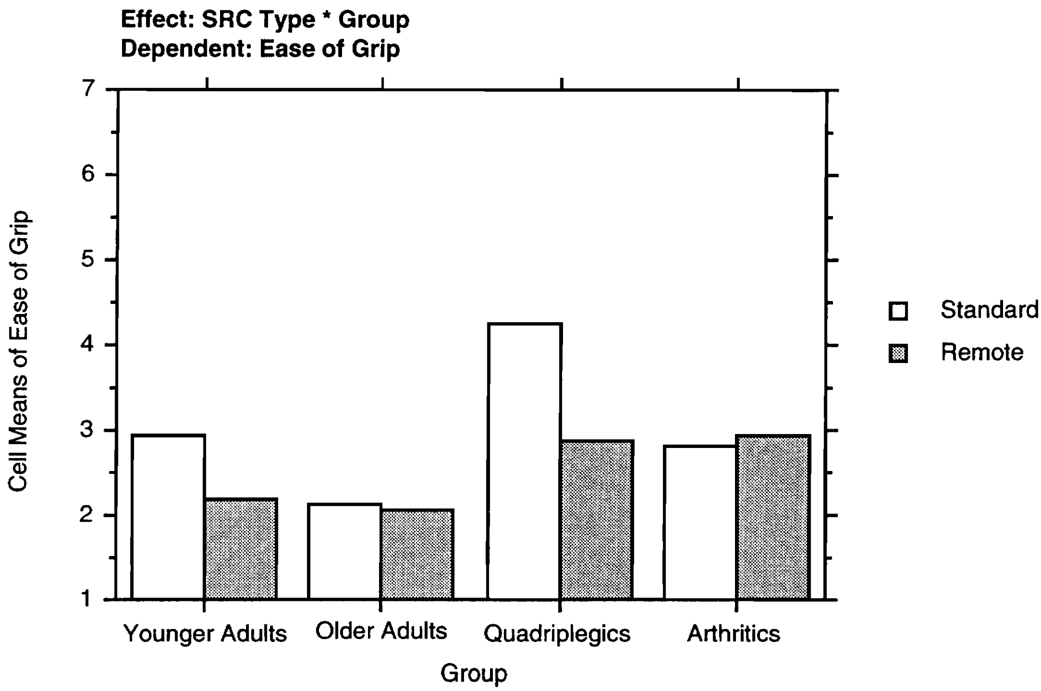

Figure 15. Group x Type of Grip Interaction on Ease of Grip

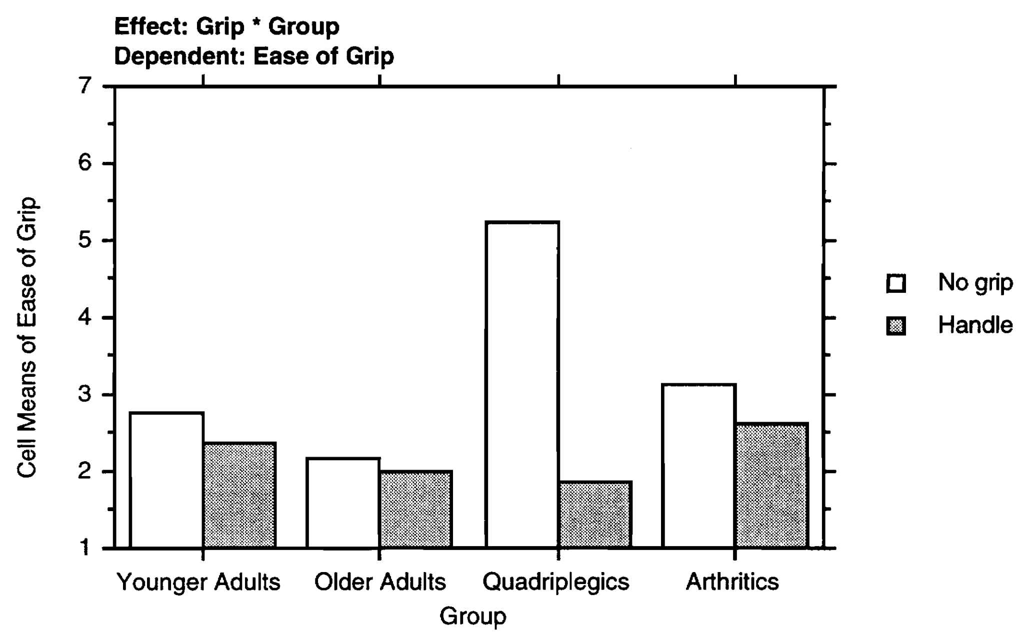

Figure 16. Group x Type of SRC Interaction on Ease of Grip

Camera Ease of Use. The results for Camera Ease of Use support the results found for Camera Stability and Camera Ease of Grip. The results of the ANOVA for the Grip Analysis are presented in Table 41. All effects are significant at the 0.05 level. The Group main effect is due once again to the significantly lower ratings given by Quadriplegics. Results of the Newman-Keuls post-hoc test and mean ratings per Group are listed in Table 42. Mean ratings per Camera are shown in Table 43, with results of the Newman-Keuls post-hoc test indicating that the Thumbsleeve camera was rated as significantly harder to use. Analysis of the significant Group x Grip interaction, plotted in Figure 17, confirms the main effects. Significant differences were detected between Quadriplegics and other groups, except for the Handle camera, which received similar ratings from all groups. Quadriplegics rated the Handle camera significantly easier to use than the other three models. Older Adults were the most severe when rating the Thumbsleeve camera. They rated it significantly harder to use than the Standard and the Rubber Pads models.

Table 41. ANOVA Summary Table for Ease of Use (Grip Analysis)

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	G-G	H-F
Group	3	167.031	55.677	8.848	.0003		
Subject(Group)	28	176.188	6.292				
Grip	3	28.406	9.469	8.389	.0001	.0004	.0001
Grip * Group	9	34.281	3.809	3.375	.0014	.0045	.0022
Grip * Subject(Group)	84	94.813	1.129				
Total	127	500.719					

Epsilon Factors

G-G Epsilon	H-F Epsilon
.749	.904

Table 42. Group Effect on Ease of Use (Grip Analysis)

Student-Newman-Keuls
Effect: Group
Significance level: .05

	Count	Mean	Std. Dev.	N-K
Older Adults	32	2.375	1.519	a
Younger Adults	32	2.500	1.107	a
Arthritics	32	3.094	2.053	a
Quadriplegics	32	5.219	1.736	b

Table 43. Mean Ease of Use Ratings per Camera

Means Table
Effect: Grip
Dependent: Use

	Count	Mean	Std. Dev.	N-K
Thumbsleeve	32	4.031	2.044	a
Standard	32	3.375	2.102	b
Rubber Pads	32	2.969	1.840	b
Handle	32	2.812	1.804	b

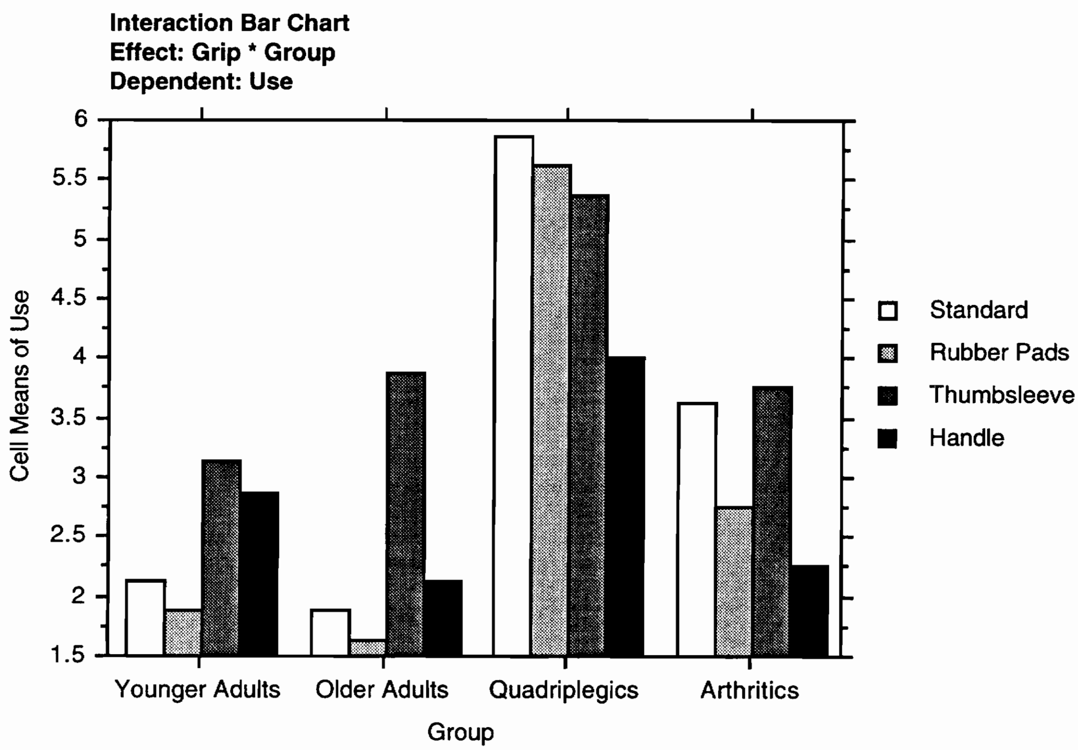

Figure 17. Group x Grip Interaction for Ease of Use

A group main effect is still present in the Grip and SRC Analysis, as can be seen in Table 44. However, a Newman-Keuls post-hoc test shows that results from Quadriplegics are significantly different from results of subjects without disabilities, but are not statistically different from the results of Arthritics. Both groups of subjects with disabilities rated the ease of use of cameras lower than the two other groups. Results of the post-hoc test and average ratings per group are presented in Table 45. The Type of SRC is also a significant main effect. The average rating for the cameras with the standard SRC is 3.09, while the one for the cameras with the remote SRC is 2.14. Analysis of the Group x Type of SRC interaction, which is also significant, shows that the remote SRC only affects Quadriplegics who rated the cameras with the standard SRC more difficult to use by 2.36 points. This difference is easily seen in Figure 18. Significant differences also exist between ratings of the standard button by Quadriplegics and by the three other groups. Figure 19 represents the Group x Type of Grip interaction. The effect of the handle is similar to the effect of the remote SRC: the handle benefits only quadriplegics and the standard grip is harder to use for Quadriplegics than for the other subjects.

Table 44. ANOVA Summary Table of Ease of Use (Grip and SRC Analysis)

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Group	3	58.398	19.466	5.918	.0029
Subject(Group)	28	92.094	3.289		
SRC Type	1	29.070	29.070	20.176	.0001
SRC Type * Group	3	29.836	9.945	6.902	.0013
SRC Type * Subject(Group)	28	40.344	1.441		
Grip	1	5.695	5.695	2.665	.1138
Grip * Group	3	26.711	8.904	4.166	.0147
Grip * Subject(Group)	28	59.844	2.137		
SRC Type * Grip	1	.633	.633	.850	.3644
SRC Type * Grip * Group	3	2.773	.924	1.242	.3132
SRC Type * Grip * Subject(Group)	28	20.844	.744		
Total	127	366.242			

Table 45. Group Effect on Ease of Use (Grip and SRC Analysis)

Student-Newman-Keuls
Effect: Group
Significance level: .05

	Count	Mean	Std. Dev.	N - K
Older Adults	32	1.781	1.039	a
Younger Adults	32	2.312	1.030	a
Arthritics	32	2.750	1.867	a b
Quadriplegics	32	3.625	2.075	b

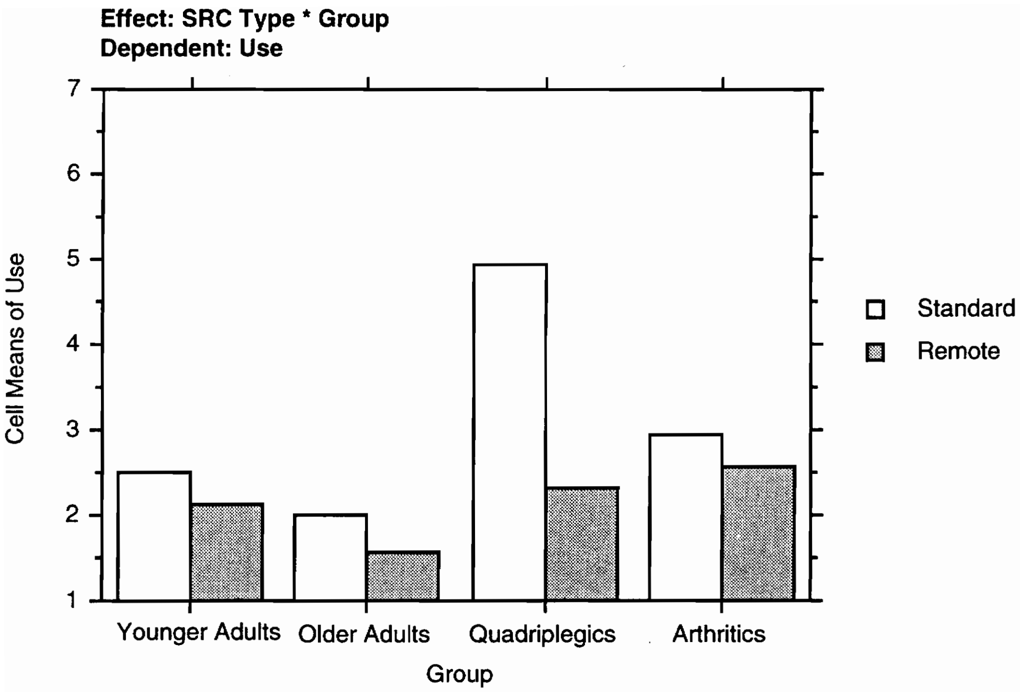

Figure 18. Group x Type of SRC Interaction for Ease of Use

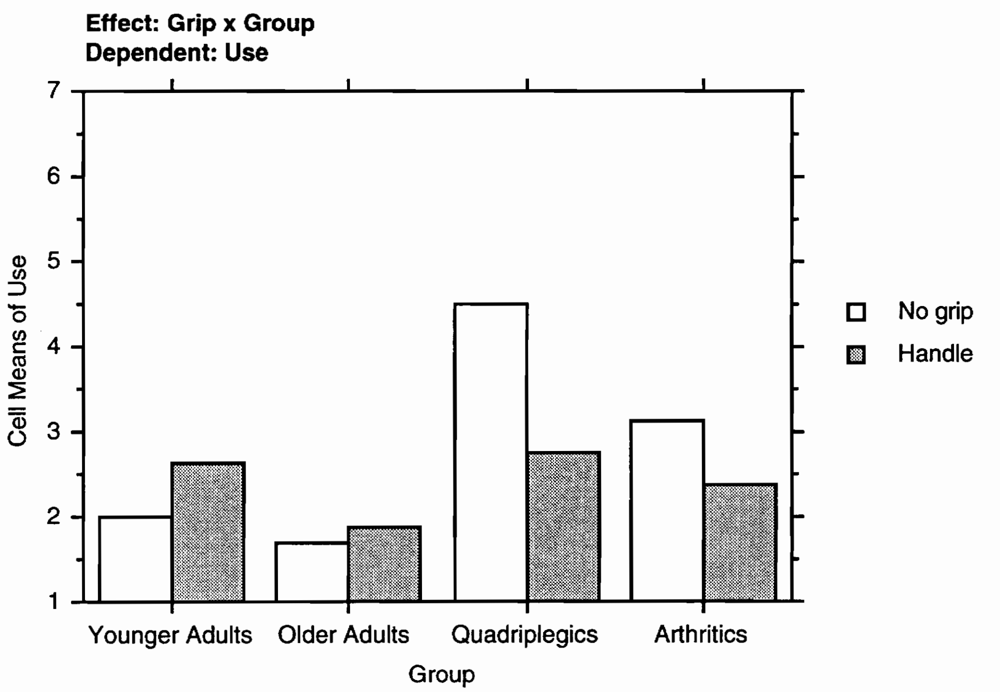

Figure 19. Group x Type of Grip Interaction for Ease of Use

Camera Ratings. Results of all six cameras were analyzed together, since subjects were asked to rate all six cameras on the same 20-point scale according to their ease of use (20 = the camera is very difficult to use, 1 = the camera is very easy to use). The ANOVA Summary Table for, presented in Table 46, shows that all effects are significant: the Group main effect, the Camera main effect, and the Group x Camera interaction. The results of the Newman-Keuls post-hoc test on the Group effect are presented in Table 47. As in Camera Ease of Use ratings, the results of Quadriplegics and Arthritics are not statistically different. Both groups gave severe overall ratings to the cameras. Results of the Newman-Keuls post-hoc test on the Camera main effect are shown in Table 48. The two cameras with the remote SRC are ranked the highest, followed by the Handle camera and the Rubber Pads camera. The Standard and the Thumbsleeve models are rated significantly harder to use than the other models. Subjects find the cameras easy to use in general. However, this can be analyzed more closely by conducting Newman-Keuls post-hoc tests on the Group x Camera interaction, plotted in Figure 20.

Figure 20 shows how, as a Newman-Keuls post-hoc test on the interaction indicates, quadriplegics rated the Standard camera and the Rubber Pads camera differently than the other groups. The other cameras were rated similarly by all groups. However, ratings vary within each group. Quadriplegics spread the cameras more towards the extremes of the scale. Differences among cameras for Quadriplegics detected by the Newman-Keuls post-hoc test on the Group x Camera interaction are shown in Table 49. Other groups rated all cameras similarly, with the exception of Older Adults rating the Thumbsleeve Camera more severely than the Rubber Pads, the Remote SRC, and the Remote SRC and Handle cameras.

Table 46. ANOVA Summary Table for Camera Ratings

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	G-G	H-F
Group	3	580.042	193.347	3.696	.0233		
Subject(Group)	28	1464.875	52.317				
Cameras	5	1028.729	205.746	13.786	.0001	.0001	.0001
Cameras * Group	15	930.896	62.060	4.158	.0001	.0001	.0001
Cameras * Subject(Group)	140	2089.375	14.924				
Total	191	6093.917					

Epsilon Factors

G-G Epsi...	H-F Epsilon
.745	.965

Table 47. Group Effect on Camera Ratings

Student-Newman-Keuls
Effect: Group
Significance level: .05

	Count	Mean	Std. Dev.	N - K	
Older Adults	48	5.854	5.454	a	
Younger Adults	48	6.688	4.121	a	
Arthritics	48	7.917	5.932	a	b
Quadriplegics	48	10.458	5.950		b

Table 48. Camera Effect on Camera Ratings

Means Table
Effect: Camera
Dependent: Rankings

	Count	Mean	Std. Dev.	N-K		
Thumbsleeve	32	10.812	5.171	a		
Standard	32	10.375	6.676	a	b	
Rubber Pads	32	7.688	6.260		b	
Handle	32	7.531	4.593		b	
Remote SRC	32	5.500	3.646			c
Remote SRC + Handle	32	4.469	4.303			c

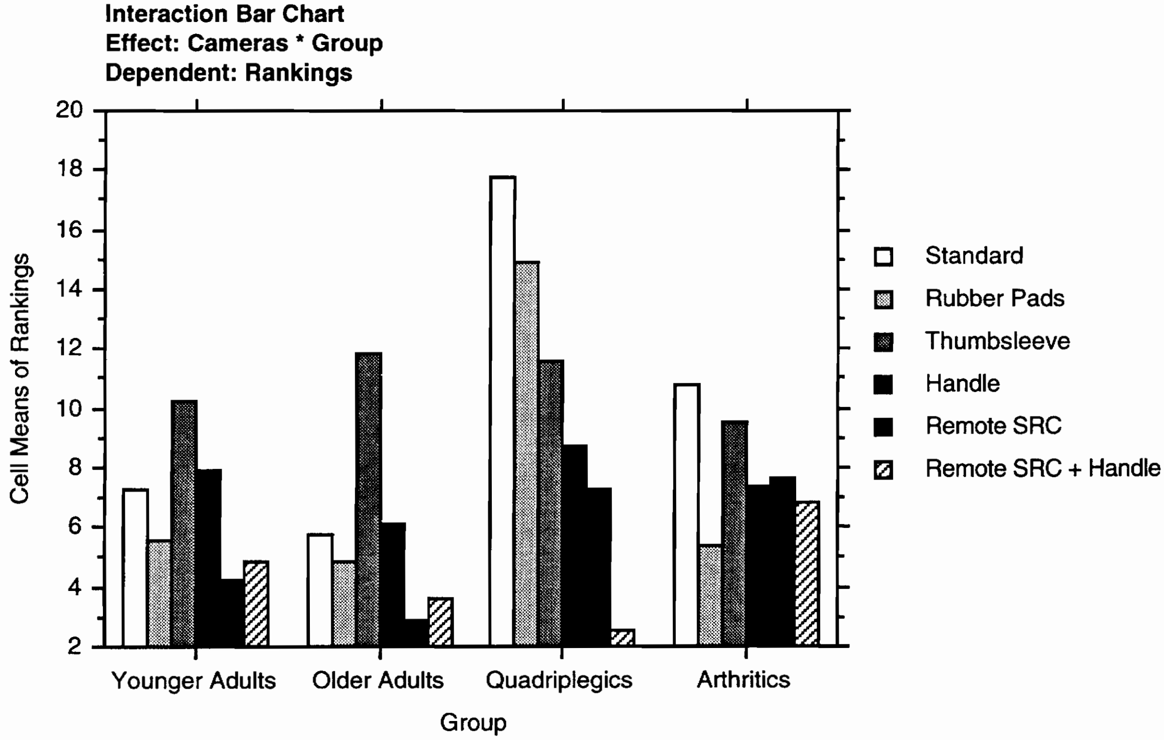

Figure 20. Group x Camera Interaction for Camera Ratings

Table 49. Differences Among Cameras for Quadriplegics

	Mean	Std. Dev.	N-K			
Standard	17.750	6.676	a			
Rubber Pads	14.875	6.260	a	b		
Thumbsleeve	11.625	5.171		b	c	
Handle	8.750	4.593			c	d
Remote SRC	7.250	3.646			c	d
Remote SRC + Handle	2.500	4.303				d

Subjective Comments. A short interview session followed the camera ratings, during which subjects were invited to give any comments or suggestions they might have about the cameras. They were also asked a few more specific questions, about the handle or the remote SRC (see Appendix F). Comments on the cameras confirmed the ratings, and were actually viewed by subjects as a way of giving a rationale for their ratings.

Subjects were asked if they thought the handle should be an accessory to the camera or permanently attached to it. A majority of them would like it as an accessory (whether disabled or non-disabled subjects). Answers to this question are shown in Table 50.

Table 50. Handle as an Accessory or Attached to the Camera

Group	Should be an accessory	Comments for the handle as an accessory	Comments for the handle to be attached on the camera
Younger Adults	6	"Too big for such a small camera" "This way, if you don't want it, you don't have to buy it" "Wouldn't use it, but can understand others would want it" "Should be able to detach it, or flip it, to keep the camera pocketable when needed"	"Would be more attractive if in camera design" "Flipable handle, with button on it would be a good idea."
Older Adults	6	"Don't see any personal use for it" "Would use it sometimes" "Accessory probably allows more 'customization'. Keep the handle so that it can swivel"	"If accessory, would not take the time to put it on. Would have to be flipable to respect camera's size" "would like it to fold in body of the camera"
Quadriplegics	6	"Waste of money to give one to everybody" "Could fit more than one model. The handle might become too small if designed in camera" "Accessory will allow more flexibility and customization, but have it look like part of the camera." "Might share the camera with others who don't want the handle"	"Risk of losing the handle" "Flipable handle would be easier. But keep the strap"
Arthritics	5	"If attached to the camera, the handle would probably have to be smaller, which I don't want" "No use now, but would be useful when my arthritis gets worse" "allows more adaptability" "No use for it personally"	"Avoids assembly. Would have to be stored more easily" "No risk of losing any part" "Too cumbersome as it is now, wants it attached and foldable"

Subjects were also asked if they would use a remote shutter release control as the one used in the study or even a wireless remote one. Answers are listed in Table 51. Quadriplegics were the only group to largely support such an idea. Many others would accept only a wireless remote button.

Table 51. Use of Remote Shutter Release Control

Group	Would use a remote SRC	Supportive of the remote SRC	Against remote SRC
Younger Adults	4	"Would use it only if wireless" "Put it on a ring, so it won't get lost and is always on hand" "Could be used for self-portraits"	"Need both hands on camera"
Older Adults	2	"With a tripod" "Great if wireless for self-portraits"	"Afraid of losing it" "It's a simple camera: keep it simple!"
Quadriplegics	8	"Leaves the camera stable in hand: no risk of moving it when pushing on the button" "Could be a 'plug in' device" "Make it water proof so that it can be placed in the mouth" "If placed on the wheelchair, no risk of activating the button when trying to grip the camera and bring it to eye-level" "Can keep balance if one arm is down" "If wireless, could even stick it on a shirt" "Would use a totally wireless one, if I can make sure the camera is stable in my left hand"	
Arthritics	1		"Afraid of inadvertent activation" "Need two hands on camera anyway to stabilize it" "Would just be something else to lose"

Discussion

Users with Special Needs

The most consistent result from the data analysis is the recurrent difference between Quadriplegics and the other groups, especially groups of non-disabled subjects. Quadriplegics performed significantly lower in framing tilt and camera shake than other subjects. They have the highest frequency of finger over the lens and rated the cameras significantly more severely than other groups on all scales but the SRC Ease of Reach. They ranked the cameras significantly lower on average than people without disabilities. These results support the results of Phase I, and confirm that people with disabilities need a more accessible camera.

Camera Modifications

The results from Phase III detail the effects of the different camera modifications on each group of subjects. They show in particular how the addition of the handle or the remote chutter release control was beneficial to quadriplegics.

Shutter Release Control. One of the major conclusions is that the remote shutter release control is an important improvement to the accessibility of the camera used in this experiment. All subjects, even the most severely disabled ones, were able to use the cameras with the remote shutter release control while three subjects were unable to use the standard camera. Results from Wilcoxon-Mann-Whitney tests on the performance measurements indicate that there are no differences in picture quality among groups when the remote SRC is on the camera. The Type of SRC has a significant main effect on all subjective ratings. The Type of SRC x Group interaction is also significant for all variables except the SRC Ease of Reach ratings. These interaction effects are always due to the positive effect the remote SRC has for Quadriplegics.

There are multiple explanations for the success of the remote SRC since it differs from the standard button in many ways:

- It offers less resistance and is easier to trigger.
- It can be placed anywhere on the camera or can be used away from the camera, such as on a wheelchair armrest or in the hand.
- It is thicker and bigger than the standard button which is flush with the camera.

Although the exact contribution of each of these characteristics to the success of the remote SRC cannot be obtained from the study, results from experiments in both Phases I and III point out how in general the shutter release control is a major barrier on cameras for quadriplegics.

According to the manufacturer's specifications, the force required to activate the standard SRC is 1.10 lb (4.89 N), which is largely under the maximum recommended operating force for a finger push found in the literature. In fact, Steinfeld and Mullick (1990) recommend that pushbuttons do not call for more than a 3 lb (13.34 N) force (more than twice the force required here) when they are to be used by people with hand or arm impairments. However, based on the subjects' comments and reactions, it appears that the force needed to push the standard SRC was the biggest blocking problem in this experiment. All disabled subjects, quadriplegics as well as arthritics, appreciated the low resistance offered by the remote SRC. The results of this study seem to call for a reevaluation of the values found in the literature, at least for small pushbuttons on hand-held products requiring a vertical finger push.

The possibility of having the SRC on the wheelchair or in other flexible locations is mostly appreciated and used by the most severely disabled subjects (C6-C7 spinal cord injury or higher). Two quadriplegic subjects even suggested a mouth activated remote SRC. They noted how the remote SRC allows them to leave one hand down to help them keep their balance. Placing the button on the back of the camera, or on the side, where it could be reached with one's thumb or wrist was also very popular among quadriplegics. Five out of eight quadriplegics placed the remote SRC in one of these positions.

The remote SRC is also particularly helpful for those subject who have had wrist surgery, due to arthritis and cannot bend their wrists. The standard top right position is hard to reach for them, thereby forcing them in awkward positions in which they cannot apply a fully vertical motion on the button. However, no general consensus on the ideal SRC location was found among arthritics.

Another advantage of the remote SRC, which many subjects of all groups pointed out is that it is thick and is more prominent than the standard one. This makes it much easier to find the SRC and keep a finger on it. Raising the SRC is a request from seven out of the eight quadriplegics tested in the study and supports comments made by quadriplegic subjects in Phase I.

Handle. The addition of the handle on the camera has a positive effect on Camera Shake, Ease of Grip, Camera Stability, and SRC Ease of Push. Main effects and interaction effects are always due, at least in part, to the beneficial effect of the handle for Quadriplegics. The handle actually allowed two of these subjects to overcome the blocking barriers they had encountered with the Standard model, the Rubber Pads model, and the Thumbsleeve model. The grip that the handle offers allowed the users to hold the camera more stable when pushing on the standard SRC. This confirms conclusions from Phase I, where it was suggested that the problem subjects had in taking pictures with the cameras was not only pushing the SRC, but having a grip good enough on the camera to push harder on the SRC.

For people with arthritis, the effect of the handle is less obvious. Although subjects in this group did rate the cameras with the handle as easier to use than the ones without the handle, there is no consensus within the group. The handle is harder to use for those subjects that had wrist surgery. Holding the handle requires bending of the wrist which these people cannot do. On the other hand, subjects with arthritis in the knuckles, have problems holding a small slippery device as a camera and rate the handle very positively.

Subjects without disabilities reacted differently to the handle. Although they did rate the cameras with the handle as slightly easier to grip and easier to stabilize, they do not think they are easier to use. Subjects' comments reveal that even if the handle offers a better grip, additional steps are required to put it on the camera or slide the hand in the Velcro strap. In fact, the handle does not have any significant effect on their performance. They do not feel the need for increased stability. For these subjects the drawbacks of the handle outweigh its advantages.

All groups agree when asked if the handle should be offered as an accessory or should be included in the design of the camera itself. The accessory option is a preferred solution by more than 70% of subjects. The rationale for people who did not like the handle is easy to understand. Since they would not use such a handle, they do not want to have it permanently attached to the camera. Those who did like the handle, on the contrary, wanted it as part of the camera. They required something 'flipable', conform to the current small size of the camera and its pocketability. Many quadriplegics feared that if the handle was designed as part of the camera, it would no longer be flexible and adjustable enough for their needs. Their comments point out that adjustability is important to them.

The results obtained with the handle are consistent with some of the existing research on grips and people with manual impairments (Steinfeld and Mullick, 1990). However, they can also be seen as contradicting the principles of universal design. What is easier for people with disabilities in this case, does not seem to be easier for other people. This research contradicts the recommendation by Vanderheiden and Vanderheiden (1992) that a "in the box design" is always preferable to having the manufacturer provide accessories for customers with disabilities. As shown in Phase I, the nature of the usability problems of the camera is different for each group. For people without disabilities, the issue is having a camera that is easy to use. For people with disabilities, the issue is having a camera that is usable at all. Therefore, allowing users to "customize" their camera according to the level of their disabilities is probably more efficient in solving usability problems for all users.

Other Models. The Thumbsleeve Camera was rated significantly harder to use and grip by older subjects. It helped quadriplegics in gripping the camera but not in stabilizing, nor using it. This might be due to the material used for the model. Many of the quadriplegics felt the Velcro was not strong enough to support the camera only with their thumb. One subject said that such a camera design would be a perfect solution for him if a solid plastic ring was used instead of the Velcro sleeve. The placement of the two Velcro pads offered to attach the thumbsleeve was such that the thumbsleeve was often either in front of an eye or bumping into the user's nose. This is particularly a problem for users with glasses.

The only subjects on which the Rubber Pads model has an effect are arthritics who rank this camera as the easiest to use and to grip. When asked if they thought the camera was easier to grip because of the rubber pads, or because it was slightly thicker than other models, all subjects answered that the rubber pads were the most helpful. In other groups however, some subjects did not even notice any difference with the Standard Camera until the rubber pads were actually pointed out to them. It is also interesting to note that quadriplegics care little about the Rubber Pads. Most of them grip the camera in "unorthodox" ways, such as resting the camera in the palm of one's hand. Consequently, they often do not even touch the rubber pads. The rubberized texture would have to cover the entire body of the camera for all subjects to notice it. This result comes as a surprise, since the location of the pads was chosen based, in part, on suggestions and recommendations of quadriplegic subjects tested during Phase I.

Summary

According to the results of Phase III, this study has lead to the design of camera models that allow subjects with disabilities to overcome accessibility barriers on the camera, and take pictures of a similar quality as the pictures taken by non-disabled subjects. Changing the shutter release control and adding a handle are successful modifications for quadriplegics, who could not otherwise use the camera in a satisfying way. Results also show how flexibility and adjustability of a device are the keys to universal product acceptance.

DISCUSSION AND CONCLUSIONS

Design Methods

The interest of this research resides not only in the data collected through the experiments, but also in the application of some well-known concepts in human factors to the specific problem of designing a product accessible to users with special needs. One of the purposes of this research is to seek out the specific problems that result from applying the methodology used in this study to populations with special needs. Many methods exist in human factors engineering to collect user's opinions or performances when designing a product (Vizri, 1992; del Galdo et al., 1990). However, these methods might need to be revised when they are applied to subjects with disabilities.

Sample Size

In any study involving populations with special needs, sample size will raise particular problems. Individual differences are more important among people with disabilities since the type and severity of the disabilities can vary considerably. Therefore, the population studied should be carefully specified before starting any experiment. Maximum and minimum levels of disability, as well as types of disabilities to be tested, have to be defined before starting the experiment to reduce heterogeneity among disabled subjects. In addition, using a large sample size would help compensate for individual differences. However, when studying populations with special needs, the availability of subjects becomes a problem (Institute for Consumer Ergonomics, 1981). Sample size selection requires a trade-off. In this case, eight subjects per group were tested in Phase III, and six only in Phase I, based on recommendations by Virzi (1992). These sample sizes are at the lower limit of what should be used with the methods used in this research.

Subjects with Special Needs

Special considerations have to be taken as users with special needs are tested. In this study, sessions lasted usually twice as long with quadriplegics than with other subjects. If wheelchair subjects are involved, the accessibility of the experimental setting must be ensured. Additional details, such as checking the availability of a handicapped parking spot, making sure all elevators function, or finding a table high enough for a wheelchair to be rolled under, need to be taken care of. Pilot testing the experiment with a disabled subject is recommended. The experimenter should also be aware that many subjects with disabilities will come with either a caretaker or family members.

Transportation is still a problem for many people with disabilities. Therefore, it is recommended when possible to bring the experiment to the subjects instead of asking subjects to come to the experimenter (Institute of Consumer Ergonomics, 1981). In Phase I, quadriplegics were tested at the Woodrow Wilson Rehabilitation Center, and in Phase III, arthritics were tested in the building of the Arthritis Foundation in Rochester.

Data Collection.

What data will be collected, and how it will be collected, has to be considered carefully when applying the three-phase methodology introduced in this study. When conducting Phase I, it is important to remember that the data collected will be used to design new solutions. It is, therefore, critical not to overlook anything that could be an accessibility barrier to the users. Several different methods were used simultaneously for data collection in Phase I (i.e., critical incident method, subject comments and ratings, and videotapes). The combination of all results allowed an in depth analysis of the problem. By using only one method, the complexity of the major accessibility barrier might have been ignored, thereby leading to inappropriate design solutions in Phase II.

It is important to collect performance measurements as well as subjective ratings of the cameras in Phase III. Each type of variable offers a different perspective view of the problem. Only the combination of all variables gives a clear understanding of the needs and desires of subjects. Subjective opinions can also be used for future developments and marketing of the consumer product tested.

Prototype Design

Phase II required collaboration with industrial designers or engineers. In this study, showing videotapes of disabled subjects interacting with the camera was the most efficient way to describe to the industrial designers the problems these subjects had in gripping the camera. Although results of Phase I were also presented to them in other formats, the videotape was considered most important. However, this could also present a risk. Designers could entirely rely on the cases they have seen on video, and overlook the rest of the population tested. Since individual differences are particularly large among people with disabilities, the experimenter should make sure designers do not focus only on a few cases, but understand the fundamental accessibility problems.

In Phase II, a Subject Matter Expert (SME) should be included as early as possible in the team working on the prototypes. A SME is someone who knows and works with the population studied, such as a physical therapist (PT), or an occupational therapist (OT). The expertise of this person would be of great help in selecting prototype designs and in explaining the physical limitations of subjects. The SME should, therefore, be present during the brainstorming phase and probably meet the designers and engineers designing the prototypes. Both a PT and an OT were consulted in Phase II. Their suggestions were made unfortunately too late because the prototypes were already almost finished, and no major modification could have been made.

Future Research

As many studies in human factors, the results of this study suggest additional research issues. Both Phase I and Phase III results point out how the current standard shutter release controls can be a barrier for some users. The Remote Shutter Release Control was a success in increasing the camera accessibility and was also rated positively by subjects without disabilities. However, there could be many reasons for this success. Future research is needed to identify the importance of each control characteristic in camera accessibility. The operating force of the button, its size, its location, and its shape are some of the button dimensions that need to be studied further.

Recommendations for operating forces of pushbuttons exist for users with hand impairments. However, they are not specific to hand-held products. Differences exist between the maximum force a user can apply on a pushbutton on a wall and a pushbutton on a hand-held product. Future research should be done to refine the current recommendations on pushbutton activation forces, depending on direction of the push and the surface the button is on.

Although this study deals with the particular problem of camera accessibility for people with manual impairments, the methodology used was designed to be applicable to any interface between a consumer product and a specific population with special needs. Conclusions on the efficiency of the methodology cannot be gained from this study alone. However, this methodology did lead to significant increases in camera accessibility and it should be applied in other cases of product design for users with special needs.

Conclusion

This study has two purposes. One is to adapt a small compact NSLR camera to users with manual impairments. The other is the application of a new three-phase methodology in designing consumer products for users with special needs. Therefore, two sets of conclusions can be drawn from the study.

The significant results obtained in the experiments demonstrate the improvement in camera accessibility that were obtained for users with manual impairments and quadriplegics in particular. The addition of a handle on the camera and the addition of a remote shutter release control were shown to be two alternatives to the standard camera design that significantly improve picture quality and subjective ratings of the camera for quadriplegics. The beneficial effect of a handle on a hand-held product for people with manual impairments is not a new result and has been used in rehabilitation. However, the difficulties subjects had with the shutter release control on the camera emphasize the need for further research to find alternatives for pushbuttons on hand-held products.

The simple fact that some accessibility barriers were reduced on the camera tends to indicate that the three-phase methodology applied in this study is efficient in finding design solutions. However, this study deals with a specific topic, and further tests of the methodology are necessary to confirm its efficiency and usefulness in designing consumer products for users with special needs. The methodology is far from being perfect and improvements of the methods used in the different phases are necessary. Hopefully, the field of designing consumer products for users with special needs will develop and expand in the coming decades.

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APPENDIX A

Virginia Polytechnic Institute and State University
Department of Industrial and Systems Engineering

Evaluation of a Non Single Lens Reflex Camera

Informed Consent Form for the Participants

The purpose of this study is to design a new Non Single Lens Reflex (NSLR) camera that will be easier to use by people with manual impairments than the current camera model used in this experiment. Before developing the new camera, an evaluation of the current camera, and of the problems people have using it, is necessary. The research is conducted by Sophie Davoine, a graduate student in the Department of Industrial and Systems Engineering of the Virginia Polytechnic Institute and State University. Dr. Robert C. Williges, professor in the Department, and Mrs. Beverly H. Williges, Senior Research Scientist in the Department, are the Principal Investigators. This research is funded by the Eastman Kodak Company.

1. Procedure

   Your grip strength, pinch strength, and finger dexterity will first be measured. You will then be presented the camera and asked to follow the procedure described in the attached form "Procedure of the experiment". After evaluating the camera, you will be asked a few questions. Your answers will be written down by the observer. Thereby, you will not be required to write anything and you will not be limited in the length of your answers to open-ended questions.

2. Confidentiality

   The results of this study will be kept confidential. At no time will the researchers release the results to anyone other than individuals working on the project. The information you provide will have your name removed and only a subject number will identify you during analyses of the data. The audio and video tapes will be kept in a locked room, will only be reviewed by individuals working on this project, at Virginia Tech or at Eastman Kodak Co., and will be erased as soon as no longer needed.

3. Compensation

The compensation you will receive for your participation in this project will be a single use camera from Kodak. Your participation should not last more than an hour. If for any reason your session must be terminated, you will be compensated for the portion of the session completed.

4. Questions or Complaints

You should know that the Principal Investigators, Dr. R. C. Williges and Mrs. B. H. Williges, and the observer, Sophie Davoine, will answer any question you may have about your participation in this research project. You may also contact Dr. E. R. Stout, Chairman of the University's Institutional Review Board, should you have any complaint or ethical concern about this experiment.

5. Withdrawal

You should know that you are free to withdraw from this study at any time, for any reason, without penalty. If you chose to do so, you will still be compensated for the portion of the session you completed.

6. Results

If you are interested in the results of this study, please give your address here, so that they can be sent to you:

Street ____

City ___________________________ Zip Code ___________

I have read and understand the informed consent and conditions of this project. I have no further question about my participation in this study. I hereby give my consent to participate, but I understand that I may stop my participation at any time if I wish to do so.

Signature ______________________________

For the subject to keep

I have read and understand the informed consent and conditions of this project, I have no further question about my participation in this study. I hereby give my consent to participate, but I understand that I may stop my participation at any time if I wish to do so.

Should I have any questions about this research or its conduct, I can contact:

Sophie Davoine	(703) 552-7618
Dr. Robert C. Williges	(703) 231-6270
Mrs. Beverly H. Williges	(703) 231-4928

Dr. Ernest R. Stout (703) 231-9359
Chair, IRB
Research Division

Supplement to the informed consent in case of videotaping:

You will be videotaped during this session. The tapes will be used to analyze hand postures and camera usability. Your name will not be attached to the videotape to respect your anonymity. You are free to withdraw your taped data from the study for any reason. If you wish to withdraw your tape from the study, please tell the observer during the session. There will be no way to differentiate your tape from others after the session. The tapes will be destroyed as soon as no longer needed.

I have read the reason why I am videotaped and have no further question about it. I hereby agree to be videotaped during this session and I understand that I have until the end of the session only to withdraw my data from the experiment.

Signature ________________________________

APPENDIX B

Questionnaire for Experiment I

(This questionnaire will be used by the observer. The questions will be asked orally to the subjects and their answers recorded on the videotape and transcribed by the observer.)

Subject #_____

Please indicate the number on each scale that reflects the most appropriately your opinion about this camera:

difficult to use	1	2	3	4	5	6	7	easy to use
difficult to grip	1	2	3	4	5	6	7	easy to grip
difficult to stabilize	1	2	3	4	5	6	7	easy to stabilize

Please indicate the number that reflects the most what you think of the film loading process on this camera:

difficult to perform	1	2	3	4	5	6	7	easy to perform

Please indicate the number that reflects the most what you think of the flash opening process on this camera:

difficult to open	1	2	3	4	5	6	7	easy to open

Please indicate the number that reflects the most appropriately what you think of the shutter release control:

difficult to use	1	2	3	4	5	6	7	easy to use

On a scale from 1 to 7, 1 being the lowest and 7 the highest, how would you rate this camera in general?

1 2 3 4 5 6 7

Would you say that this camera is an acceptable or a non-acceptable product? (Please select one)

If you think it is not an acceptable product, please explain why.

____

____

____

____

What improvements would you add to this camera to increase its usability?

____

____

____

____

____

Do you currently own a camera?

Yes, I do

No, I do not

If yes, was this camera specially adapted for your needs?

Yes, it was adapted

No, it was not adapted

If your camera was adapted for your needs, can you describe how it was adapted?

____

____

Do you have any other comments on camera usability you would like to make?

____

____

____

____

____

APPENDIX C

<u>Procedure of the Experiment I</u>

You will be asked to perform the following tasks with the camera that will be presented to you:

1. Load a roll of film in the camera
2. Unobstruct the lens of the camera by opening the flash to turn the camera on
3. Take three different pictures in a row using the viewfinder
4. Close the flash to cover the lens and turn the camera off

While performing these tasks, you will be asked to report Critical Incidents. Critical Incidents occur either when you have a problem with a feature of the camera, or, on the contrary, when you like the way a feature is designed or presented on the camera. It happens whenever you would like to react, either negatively or positively, about an element of the camera. Some examples of Critical Incidents could be "the camera is difficult to grasp", or "the shutter release control is located conveniently". Report these incidents as they occur. If you do not report any incident while manipulating the camera, the observer will prompt you to report something at the end of each of the benchmark task described previously.

When reporting an incident, it is important that you give three types of information:

1. Are you reporting a success or a failure?
2. Describe the incident in detail.

   When describing the incident, try to identify the exact element of the camera that causes problem or satisfaction, and the function that is difficult or easy to perform, e.g.,

	Element	Function
e.g.,	"the shutter release control"	"is hard to activate"
	"the viewfinder"	"allows easy framing"

3. Rate the severity of the incident on the following scale.

1	2	3	4	5	6	7
Least severe						Most severe

The observer will remind you of the types of information you must give for each incident if you happen to omit something. You will still be able to add further comments and make suggestions in the short interview that will follow the performance of these tasks.

APPENDIX D

Task Analysis of the Camera

Tasks	Sub-tasks	Abilities involved
Load film in the camera	Grip the camera Turn it face down Find door latch Open the door Place the battery in Close the door	Grip strength Grip strength (wrist motion) Cognitive abilities Finger strength and dexterity Pinch strength and finger dexterity Finger strength
Getting the film	Grab canister Open canister Get the roll of film out of the canister	Grip strength Finger strength Finger dexterity
Load film in the camera	Grip the camera Turn it face down Find door latch Open the door Take the roll of film Pull the leader out Orient film and push it in the camera Secure leader Close the door Press shutter release control	Grip strength Grip strength (wrist motion) Cognitive abilities Finger strength and dexterity Grip or pinch strength Finger dexterity and pinch strength Finger dexterity Finger dexterity Finger strength Finger strength
Open the flash	Hold the camera Turn the camera face up Find the latch Pull to open the flash	Grip strength Grip strength (wrist motion) Cognitive abilities Finger strength

Take picture(s)	Grab the camera Lift it to eye level Find the viewfinder Frame the scene and stabilize the camera Activate the shutter release control Lower the camera	Grip strength Grip strength and arm strength Cognitive abilities Grip strength and arm strength Finger strength and dexterity Grip strength
Close the flash	Hold the camera Push on flash to close it Release the camera	Grip strength Finger strength
Unload film	Grip the camera Turn it face down Find door latch Open the door Take the roll of film out Close the door	Grip strength Grip strength (wrist motion) Cognitive abilities Finger strength and dexterity Grip and pinch strength Finger strength
Unload Battery	see Load Battery	

APPENDIX E

GROUP A: FAILURES

Element	Action	Problem	Rating	Solution(s)
Film	inserting	takes more film than what's shown in instruction	2	draw the line in a better place or be more specific in instructions
Film	inserting	roll had to be pushed in place	2	more space.
Film	inserting	cannot find the film load mark	5	does not correspond to diagram in manual
Film	inserting	spool is too complex	4	Make something where you just have to drop the film in
Film	inserting	roll not in place, had to be pushed in place	5	training, make the place for the roll larger
Flash	opening	risk of putting fingers on viewfinder	2	??
Flash	opening	difficult to find the place to grab the flash	6	put it so that it can be seen when looking at he camera from behind
Flash	closing	requires some amount of force, seems like it will break	5	make it less hard to close
SRC	locating	easy to lose it, too much like camera body	2	raise it or have a ridge around it
Viewfinder	framing with	no frame in viewfinder	2	add a frame in the viewfinder
Viewfinder	framing with	no frame or lines to help	3	add horizontal/vertical lines
Viewfinder	using	is the alignment of lenses solid	4	??

Total: 12 Failures

GROUP A: SUCCESSES

Element	Action	Success	Rating	Comments
Camera	holding	fits in hand	6	size and weight OK
Camera	holding	is adequate	2	
Film	inserting	is easy	6	
Film door	opening	the way it lifts up is nice	7	
Flash	closing	snaps easily	7	
Flash	closing	snaps easily	7	
Flash	closing	not too much resistance, goes right in	5	
Flash	closing	very easy, straightforward	7	
Flash	opening	is simple and easy	7	
Flash	opening	is easy	6	Idea is great: no risk of losing cap
Flash	opening	is easy	7	
Flash	opening	is easy	6	
Flash	opening	is easy	7	helped by silver edge
SRC	locating	easy to find	7	perfectly aligned with indentation and hinge for thumb behind
SRC	reaching	is nicer on top than in front	7	
Viewfinder	finding	is easy, right in front of eye away from camera	7	

Total: 16 Successes

GROUP B: FAILURES

Element	Action	Problem	Rating	Solution(s)
Film	inserting	sprockets are not obvious and helpful enough	3	put the sprockets on top (as in other cameras)
Film	inserting	hard to pull film when inserted in camera	3	more space, make the film loading process easier
Film	inserting	finding how far the film should be pulled out	4	Make the line more obvious
Film	inserting	where is the film line	3	Line should be more distinctive and colored
Film door	finding	the latch is hard to find	4	make the latch bigger
Film door	finding	latch is hard to find	6	make it color coded, plus label with "OPEN" for example
Film door	finding	latch is hard to find	3	Make it red(?)
Film door	opening	have to push on latch instead of pulling	2	make the latch so you have to pull on it, or make arrow more obvious (color it)
Flash	charging	no indicator in viewfinder	1	add a light (sign on LCD is not clear either)
Flash	charging	indication not clear enough	2	something in viewfinder
Flash	opening	putting fingers on flash as opening it	1	if risks of making it dirty
Flash	opening	latch difficult to find	2	No indication of where to open flash when looking at the back of the camera
Flash	opening	latch is hard to find	4	color code plus label
SRC	pushing	might be too easy to push	4	wish there was a lock on the button in case of kids playing with camera
Viewfinder	framing with	no frame in the viewfinder	3	Add a frame or make it clear that what you get is what you see

Total: 15 Failures

GROUP B: SUCCESSES

Element	Action	Success	Rating	Comments
Camera	holding	easy because light	7	
Camera	holding	easy because good size	7	
Camera	holding	good weight	6	
Camera	holding	good size	6	
Camera	holding	good size	7	can be carried in pocket
Camera	holding	no risk of covering flash with fingers	5	
Film	inserting	is easy	6	
Film	loading	likes the rewinding + is fast	7	
Film	advancing	is automatic	7	
Flash	closing	easy, locks tight	5	
Flash	closing	easy, well made	7	
Flash	closing	easy and multifunctional	6	Turns the camera off, easy to remember.
Flash	closing	Extremely easy	7	
Flash	closing	real easy	7	
Flash	opening	is easy with picture on the manual	7	
Flash	opening	is easy	7	looks nice with flash open
Flash	opening	easy, smooth	6	no risk of catching something
Flash	opening	easy	7	
SRC	locating	large enough	7	no need to feel around
SRC	locating	easy to find- distinct from the rest - only one	7	
Viewfinder	finding	easy because away from the camera	7	
Viewfinder	using	is clear, looks good	7	

Total: 22 Successes

GROUP C: FAILURES

Element	Action	Problem	Rating	Solution(s)
Camera	grasping	Camera "slips" too much	5	add ridges
Camera	grasping	Camera body is too "smooth"	4	make finger notch larger, or make the camera textured
Film	inserting	does not fall in place alone	2	?
Film	inserting	not enough room	2	make space for roll of film slightly larger
Film Door	finding	latch is too small	4	make it larger and wider
Film Door	opening	latch too small	3	extend the latch
Film Door	opening	latch too small and "crowded"	4	Have the latch stick out more and more room
Film Door	opening	latch is too small	4	make it wider
Film Door	opening	pushing latch	4	pulling would be easier(with one hand), make a pushbutton like shutter release
Film Door	opening	latch too small	4	make it larger and wider
Flash	opening	too much resistance	4	Have it spring more
SRC	pushing	too much force required	7	reduce the resistance, add a ridge around it on the side of the LCD to prevent finger from slipping
SRC	pushing	too much force required	2	Lighten up the button a little
SRC	pushing	too much force required	5	Lighten up the SRC, place it on back so that it can be pushed with thumb (strongest finger)
SRC	reaching	bad location	7	Put the button on the side

Total: 15 Failures

GROUP C: SUCCESSES

Element	Action	Success	Rating	Comments
Camera	holding	good weight	6	
Camera	holding	good weight	7	great feeling
Camera	holding	good weight	7	
Camera	holding	use of edge	7	
Camera	holding	use of curve for finger	6	
Flash	closing	easy action	6	
Flash	closing	is easy	7	
Flash	closing	is easy	7	
Flash	closing	is easy	7	snaps with a finger
Flash	closing	is easy	7	real easy
Flash	opening	easy	7	weight of the camera stays balanced even with flash open
Flash	opening	flips up easily	7	
Flash	opening	lifts easily	6	the notch should be larger though
Flash	opening	is easy	7	
Flash	opening	easy to pull once opened	7	
LCD	seeing	easy because is big	7	
Viewfinder	using	the curve of the viewfinder is nice	7	Can rest eyebrow on the curve (?)

Total: 17 Successes

GROUP D FAILURES

Element	Action	Problem	Rating	Solution(s)
Camera	holding	The camera is too small to have a good grip on it	3	Make indentations deeper and edges wider, with a larger radius
Camera	holding	difficult to hold the camera with just left hand	4	
Film	loading	Had to lay the camera down	3	could not hold it long enough => grip problem
Film	loading	feels like forcing the roll in	3	
Film	loading	picture on instruction manual is not good	3	get a better drawing
Film Door	opening	Pulling latch instead of pushing on it	1	Underline it in the manual. After doing it once, it is OK.
Film Door	opening	had to open the latch with fingernail	4	make an up/down latch on the side to release the door
Film Door	opening	latch is too small, requires fingernail	3	make it larger
Flash	opening	latch is too small, requires effort to open	2	have an automatic opening of the flash
SRC	locating	slightly too small	1	make it bigger
SRC	locating	is not obvious when taking a vertical position	2	put the SRC in the front or change its texture, but don't raise it.
Viewfinder	using	Can see the sides of the flash in the viewfinder	3	Even if does not appear on pictures, the flash should be larger.

Total: 12 failures

GROUP D SUCCESSES

Element	Action	Success	Rating	Comments
Camera	holding	easy	7	nice size and goes into a pocket
Camera	holding	easy because very light	7	
Camera	holding	easy because of roundness + nothing sticking out	7	Not cumbersome; texture could be rougher where fingers are
Camera	holding	fingers fit well, good grasp	6	indentations are well placed
Camera	holding	has a good grip even with large hands	7	comfortable
Camera	holding	notch is a good reminder of where to put fingers	7	
Film	inserting	was easy (first time ever done it)	7	
Film	inserting	was easy (first time done it too)	7	
Flash	closing	easy, although might think you will break it	7	
Flash	closing	easy	7	
Flash	closing	relatively easy	6	slightly harder than opening it though
Flash	closing	is very easy	7	
Flash	opening	easy, neat	7	protects the lens
Flash	opening	easy	7	
Flash	opening	is easy because the latch is large	7	
Flash	opening	easy to understand and do	7	
SRC	locating	is easy	7	color and contour makes it easy to find
SRC	locating	good location	6	better on top than in front, easier to find that way
SRC	pushing	easy because large enough	6	large enough even for large hands

Total: 19 successes

APPENDIX F

Questionnaire of Experiment III

Subject #______

Dominant hand:

Grip Strength: Right ______________ ______________

Left ______________ ______________

(For groups of subjects with disabilities only:

ADLs:

Can you brush your teeth? _____

shave or put on make-up? _____

cut meat with a knife? _____

eat with a fork? _____

manage a book or a newspaper? _____

use a telephone? _____

Rating: √ = Yes, can do it independently

A = Yes, can do it with assistance

X = No, can not do it (activity not indicated)

)

Subject #_____

This section of the questionnaire is repeated for each camera tested.

Camera Model #__1__ (Standard)

Please indicate the number on each scale that reflects your opinion about this camera:

very easy to use	1	2	3	4	5	6	7	very difficult to use
very easy to grip	1	2	3	4	5	6	7	very difficult to grip
very easy to stabilize	1	2	3	4	5	6	7	very difficult to stabilize

Please indicate the number on each scale that reflects your opinion about the shutter release control:

very easy to push	1	2	3	4	5	6	7	very difficult to push
very easy to reach	1	2	3	4	5	6	7	very difficult to reach

Camera Model #__2__ ("Rubber Pads")

Please indicate the number on each scale that reflects your opinion about this camera:

very easy to use	1	2	3	4	5	6	7	very difficult to use
very easy to grip	1	2	3	4	5	6	7	very difficult to grip
very easy to stabilize	1	2	3	4	5	6	7	very difficult to stabilize

Please indicate the number on each scale that reflects your opinion about the shutter release control:

(if different than for the other cameras)

very easy to push	1	2	3	4	5	6	7	very difficult to push
very easy to reach	1	2	3	4	5	6	7	very difficult to reach

Camera Model #__3__ ("thumbsleeve")

Please indicate the number on each scale that reflects your opinion about this camera:

very easy to use	1	2	3	4	5	6	7	very difficult to use
very easy to grip	1	2	3	4	5	6	7	very difficult to grip
very easy to stabilize	1	2	3	4	5	6	7	very difficult to stabilize

Please indicate the number on each scale that reflects your opinion about the shutter release control:

(if different than for other cameras)

very easy to push	1	2	3	4	5	6	7	very difficult to push
very easy to reach	1	2	3	4	5	6	7	very difficult to reach

Camera Model #__4__ ("handle")

Please indicate the number on each scale that reflects your opinion about this camera:

very easy to use	1	2	3	4	5	6	7	very difficult to use
very easy to grip	1	2	3	4	5	6	7	very difficult to grip
very easy to stabilize	1	2	3	4	5	6	7	very difficult to stabilize

Please indicate the number on each scale that reflects your opinion about the shutter release control:

(if different than for other cameras)

very easy to push	1	2	3	4	5	6	7	very difficult to push
very easy to reach	1	2	3	4	5	6	7	very difficult to reach

Camera Model #__5__ (1 + remote SRC)

Please indicate the number on each scale that reflects your opinion about this camera:

very easy to use	1	2	3	4	5	6	7	very difficult to use
very easy to grip	1	2	3	4	5	6	7	very difficult to grip
very easy to stabilize	1	2	3	4	5	6	7	very difficult to stabilize

Please indicate the number on each scale that reflects your opinion about the remote shutter release control:

very easy to push	1	2	3	4	5	6	7	very difficult to push
(very easy to reach	1	2	3	4	5	6	7	very difficult to reach)

Not really necessary since placed by subject?

Camera Model #__6__ (4 + remote SRC)

Please indicate the number on each scale that reflects your opinion about this camera:

very easy to use	1	2	3	4	5	6	7	very difficult to use
very easy to grip	1	2	3	4	5	6	7	very difficult to grip
very easy to stabilize	1	2	3	4	5	6	7	very difficult to stabilize

Please indicate the number on each scale that reflects your opinion about the shutter release control:

(if different than for camera 5)

very easy to push	1	2	3	4	5	6	7	very difficult to push
(very easy to reach	1	2	3	4	5	6	7	very difficult to reach)

Not really necessary since placed by subject?

For all cameras together:

Please use the prototypes on the table in front of you and order them on this scale according to your preference. In doing that please respect the relative distances between cameras.

Camera Number	Rating on scale
1	
2	
3	
4	
5	
6	

How would you improve these cameras should they be developed further?

Should the grip be developed as an adaptive device (available on demand) or should it be included in the design of the camera?

Other comments:

What methods would you recommend to mount the accessories?

Wriststrap on cameras 2 and 3?

Would you use the remote shutter release on knees, or hanging down?

Anything else?

APPENDIX G

Procedure of Experiment III
Comparative Evaluation of Non Single Lens Reflex Cameras

After a short questionnaire on your photographic habits, and measurements of your grip strength, you will be presented different models of a small autofocus compact camera. For each prototype evaluated in the experiment, you will be asked to perform the following tasks:

1. Turn the camera on by opening its flash.
2. Take a first picture of the scene. This is a practice picture to help you find the best way to hold the camera.
3. Take two pictures of the scene, aiming at the head of the dummy in the scene, and holding the camera as stable as possible.
4. Turn the camera off by closing its flash.

After taking the pictures, you will be asked different questions about the usability and the holdability of the different camera models you have tested. You will also be asked to rank the cameras in order of preference. Finally, a short "interview" will follow, where you will be invited to give any comment or suggestion that you may have about these camera models.

APPENDIX H

Significant unconfounded paired comparisons are indicated in bold type. To reduce the size of the tables to an acceptable format, factor levels were replaced by the following codes:

Group:	Younger Adults = A
	Older Adults = B
	Quadriplegics = C
	Arthritics = D
Camera:	Standard = 1
	Rubber Pads = 2
	Thumbsleeve = 3
	Handle = 4
	Remote SRC = 5
	Remote SRC + Handle = 6
Type of Grip:	Standard = Std
	Handle = Hdl
Type of SRC:	Standard = Std
	Remote = Rem

Shutter Release Control Ease of Push

Group x Type of SRC interaction (Grip and SRC Analysis)

(df = 28, n = 16, MS error = 2.419)

	Means	B-Rem	A-Rem	C-Rem	D-Rem	B-Std	A-Std	D-Std	C-Std	r	Critical Difference
Means		1.125	1.438	1.438	1.688	1.938	2.812	3.562	6.188		
B-Rem	1.125		0.312	0.312	0.562	0.812	1.688	2.438	5.062	8	1.82
A-Rem	1.438			0	0.25	0.5	1.375	2.125	4.75	7	1.765
C-Rem	1.438				0.25	0.5	1.375	2.125	**4.75**	6	1.699
D-Rem	1.688					0.25	1.125	**1.875**	4.5	5	1.621
B-Std	1.938						.875	**1.625**	**4.25**	4	1.516
A-Std	2.812							0.75	**3.375**	3	1.373
D-Std	3.562								**2.625**	2	1.135
C-Std	6.188										

Shutter Release Control Ease of Reach

No significant interaction

Camera Stability

Group x Type of SRC interaction (Grip and SRC Analysis)

(df = 28, n = 16, MS error = 0.735)

	Means	B-Rem	B-Std	A-Rem	D-Std	C-Rem	A-Std	D-Rem	C-Std	r	Critical Difference
Means		1.938	2.375	2.625	2.688	2.812	2.875	2.938	4.188		
B-Rem	1.938		0.437	0.687	0.75	0.874	0.937	**1**	2.25	8	1
B-Std	2.375			0.25	0.313	0.437	0.5	0.563	**1.813**	7	0.972
A-Rem	2.625				0.063	0.187	0.25	0.313	1.563	6	0.935
D-Std	2.688					0.124	0.187	0.25	**1.5**	5	0.892
C-Rem	2.812						0.063	0.126	**1.376**	4	0.835
A-Std	2.875							0.063	**1.313**	3	0.755
D-Rem	2.938								1.25	2	0.625
C-Std	4.188										

Camera Ease of Grip

Group x Grip interaction (Grip Analysis)

(df = 84, n = 8, MS error = 1.987)

	Means	D-2	A-2	B-1	B-2	B-4	C-4	D-4	A-4	A-1	D-1	B-3	A-3	D-3	C-2	C-3	C-1	r	C. D.
Means		1.75	1.75	2	2	2.25	2.375	2.625	2.875	3	3	3.75	3.75	3.875	4.875	5	6.125		
D-2	1.75		0	0.25	0.25	0.5	0.625	0.875	1.125	1.25	1.25	2	2	2.125	**3.125**	3.25	4.375	16	2.52
A-2	1.75			0.25	0.25	0.5	0.625	0.875	1.125	1.25	1.25	2	2	2.125	**3.125**	3.25	4.375	15	2.49
B-1	2				0	0.25	0.375	0.625	0.875	1	1	1.75	1.75	1.875	2.875	3	**4.125**	14	2.46
B-2	2					0.25	0.375	0.625	0.875	1	1	1.75	1.75	1.875	**2.875**	3	4.125	13	2.43
B-4	2.25						0.125	0.375	0.625	0.75	0.75	1.5	1.5	1.625	2.625	2.75	3.875	12	2.395
C-4	2.375							0.25	0.5	0.625	0.625	1.375	1.375	1.5	**2.5**	**2.625**	**3.75**	11	2.356
D-4	2.625								0.25	0.375	0.375	1.125	1.125	1.25	2.25	2.375	3.5	10	2.316
A-4	2.875									0.125	0.125	0.875	0.875	1	2	2.125	3.25	9	2.266
A-1	3										0	0.75	0.75	0.875	1.875	2	**3.125**	8	2.211
D-1	3											0.75	0.75	0.875	1.875	2	**3.125**	7	2.146
B-3	3.75												0	0.125	1.125	1.25	2.375	6	2.072
A-3	3.75													0.125	1.125	1.25	2.375	5	1.982
D-3	3.875														1	1.125	2.25	4	1.863
C-2	4.875															0.125	**1.25**	3	1.693
C-3	5																**1.125**	2	1.409
C-1	6.125																	1	

Group x Type of SRC interaction (Grip and SRC Analysis)

(df = 28, n = 16, MS error = 0.856)

	Means	B-Rem	B-Std	A-Rem	D-Std	C-Rem	A-Std	D-Rem	C-Std	r	Critical Difference
Means		2.062	2.125	2.188	2.812	2.875	2.938	2.938	4.250		
B-Rem	2.062		0.063	0.126	0.75	0.813	0.876	0.876	**2.188**	8	1.081
B-Std	2.125			0.063	0.687	0.75	0.813	0.813	2.125	7	1.049
A-Rem	2.188				0.624	0.687	0.75	0.75	**2.062**	6	1.009
D-Std	2.812					0.063	0.125	**0.125**	**1.438**	5	0.963
C-Rem	2.875						0.063	0.063	**1.375**	4	0.901
A-Std	2.938							0	1.312	3	0.815
D-Rem	2.938								**1.312**	2	0.674
C-Std	4.250										

Group x Type of Grip interaction (Grip and SRC Analysis)

(df = 28, n = 16, MS error = 4.044)

	Means	C-Hdl	B-Hdl	B-Std	A-Hdl	D-Hdl	A-Std	D-Std	C-Std	r	Critical Difference
Means		1.875	2	2.188	2.375	2.625	2.75	3.125	5.25		
C-Hdl	1.875		0.125	0.313	0.5	0.75	0.875	1.25	3.375	8	2.354
B-Hdl	2			0.188	0.375	0.625	0.75	1.125	**3.25**	7	2.284
B-Std	2.188				0.187	0.437	0.562	0.937	3.062	6	2.198
A-Hdl	2.375					0.25	0.375	**0.75**	**2.875**	5	2.098
D-Hdl	2.625						0.125	0.5	**2.625**	4	1.962
A-Std	2.75							0.375	**2.5**	3	1.776
D-Std	3.125								**2.125**	2	1.469
C-Std	5.25										

Camera Ease of Use

Group x Grip interaction (Grip Analysis)

(df = 84, n = 8, MS error = 1.129)

	Means	B-2	A-2	B-1	A-1	B-4	D-4	D-2	A-4	A-3	D-1	D-3	B-3	C-4	C-3	C-2	C-1	r	C.D.
Means		1.625	1.875	1.875	2.125	2.125	2.250	2.750	2.875	3.125	3.625	3.750	3.875	4.000	5.375	5.625	5.875		
B-2	1.625		0.250	0.125	0.375	0.375	0.500	1.000	1.125	1.375	1.875	2.000	**2.125**	2.250	3.625	**3.875**	4.125	16	1.903
A-2	1.875			0.125	0.375	0.375	0.500	1.000	1.125	1.375	1.875	2.000	2.125	2.250	3.625	**3.875**	4.125	15	1.88
B-1	1.875				0.125	0.125	0.250	0.750	0.875	1.125	1.625	1.750	**1.875**	2.000	3.375	3.625	**3.875**	14	1.857
A-1	2.125					0.125	0.250	0.750	0.875	1.125	1.625	1.750	1.875	2.000	3.375	3.625	**3.875**	13	1.835
B-4	2.125						0.000	0.500	0.625	0.875	1.375	1.500	1.625	1.750	3.125	3.375	3.625	12	1.809
D-4	2.250							0.375	0.500	0.750	1.250	1.375	1.500	1.625	3.000	3.250	3.500	11	1.778
D-2	2.750								0.250	0.500	1.000	1.125	1.250	1.375	2.750	**3.000**	3.250	10	1.748
A-4	2.875									0.250	0.750	0.875	1.000	1.125	2.500	2.750	3.000	9	1.711
A-3	3.125										0.625	0.750	0.875	1.000	**2.375**	2.625	2.875	8	1.669
D-1	3.625											0.750	0.875	1.000	2.375	2.625	**2.875**	7	1.621
D-3	3.750												0.125	0.250	**1.625**	1.875	2.125	6	1.564
B-3	3.875													0.250	**1.625**	1.875	2.125	5	1.496
C-4	4.000														**1.500**	**1.750**	**2.000**	4	1.406
C-3	5.375															0.750	1.000	3	1.278
C-2	5.625																0.875	2	1.064
C-1	5.875																	1	

Group x Type of SRC interaction (Grip and SRC Analysis)

(df = 28, n = 16, MS error = 1.441)

	Means	B-Rem	B-Std	A-Rem	C-Rem	A-Std	D-Rem	D-Std	C-Std	r	Critical Difference
Means		1.562	2	2.125	2.312	2.5	2.562	2.938	4.938		
B-Rem	1.562		0.438	0.563	0.75	0.938	1	1.376	3.376	8	1.431
B-Std	2			0.125	0.312	0.5	0.562	0.938	**2.938**	7	1.386
A-Rem	2.125				0.187	0.375	0.437	0.813	2.813	6	1.335
C-Rem	2.312					0.188	0.25	0.626	**2.626**	5	1.251
A-Std	2.5						0.062	0.438	**2.438**	4	1.17
D-Rem	2.562							0.376	2.376	3	1.059
D-Std	2.938								**2**	2	1.876
C-Std	4.938										

Group x Type of Grip interaction (Grip and SRC Analysis)

(df = 28, n = 16, MS error = 2.137)

	Means	B-Std	B-Hdl	A-Std	D-Hdl	A-Hdl	C-Hdl	D-Std	C-Std	r	Critical Difference
Means		1.688	1.875	2	2.375	2.625	2.75	3.125	4.5		
B-Std	1.688		0.187	0.312	0.687	0.937	1.062	1.437	**2.812**	8	1.708
B-Hdl	1.875			0.125	0.5	0.75	0.875	1.25	2.625	7	1.657
A-Std	2				0.375	0.625	0.75	1.125	**2.5**	6	1.595
D-Hdl	2.375					0.25	0.375	.75	2.125	5	1.522
A-Hdl	2.625						0.125	0.5	1.875	4	1.423
C-Hdl	2.75							0.375	**1.75**	3	1.288
D-Std	3.125								**1.375**	2	1.065
C-Std	4.5										

Camera Rankings

Group x Camera interaction

(df= 140, n = 8, MS error = 14.924)

	Means	C-6	B-5	B-6	A-5	A-6	B-2	D-2	A-2	B-1	B-4	D-6	C-5	A-1	D-4	D-5	A-4	C-4	D-3	A-3	D-1	C-3	B-3	C-2	C-1	r	CD
Means		2.500	2.875	3.625	4.250	4.875	4.875	5.375	5.625	5.750	6.125	6.875	7.250	7.250	7.375	7.625	7.875	8.750	9.500	10.250	10.750	11.625	11.875	14.875	17.750		
C-6	2.500		0.375	1.125	1.750	2.375	2.375	2.875	3.125	3.250	3.625	4.375	4.750	4.750	4.875	5.125	5.375	6.250	7.000	7.750	8.250	9.125	9.375	12.375	15.250	24	7.143
B-5	2.875		0.000	0.750	1.375	2.000	2.000	2.500	2.750	2.875	3.250	4.000	4.375	4.375	4.500	4.750	5.000	5.875	6.625	7.375	7.875	8.750	9.000	12.000	14.875	23	7.116
B-6	3.625				0.625	1.250	1.250	1.750	2.000	2.125	2.500	3.250	3.625	3.625	3.750	4.000	4.250	5.125	5.875	6.625	7.125	8.000	8.250	11.250	14.125	22	7.089
A-5	4.250					0.625	0.625	1.125	1.375	1.500	1.875	2.625	3.000	3.000	3.125	3.375	3.625	4.500	5.250	6.000	6.500	7.375	7.625	10.625	13.500	21	7.048
A-6	4.875						0.000	0.500	0.750	0.875	1.250	2.000	2.375	2.375	2.500	2.750	3.000	3.875	4.625	5.375	5.875	6.750	7.000	10.000	12.875	20	7.007
B-2	4.875							0.500	0.750	0.875	1.250	2.000	2.375	2.375	2.500	2.750	3.000	3.875	4.625	5.375	5.875	6.750	7.000	10.000	12.875	19	6.952
D-2	5.375								0.250	0.375	0.750	1.500	1.875	1.875	2.000	2.250	2.500	3.375	4.125	4.875	5.375	6.250	6.500	9.500	12.375	18	6.884
A-2	5.625									0.125	0.500	1.250	1.625	1.625	1.750	2.000	2.250	3.125	3.875	4.625	5.125	6.000	6.250	9.250	12.125	17	6.829
B-1	5.750										0.375	1.125	1.500	1.500	1.625	1.875	2.125	3.000	3.750	4.500	5.000	5.875	6.125	9.125	12.000	16	6.761
B-4	6.125											0.750	1.125	1.125	1.250	1.500	1.750	2.625	3.375	4.125	4.625	5.500	5.750	8.750	11.625	15	6.693
D-6	6.875												0.375	0.375	0.500	0.750	1.000	1.875	2.625	3.375	3.875	4.750	5.000	8.000	10.875	14	6.611
C-5	7.250													0.000	0.125	0.375	0.625	1.500	2.250	3.000	3.500	4.375	4.625	7.625	10.500	13	6.529
A-1	7.250														0.125	0.375	0.625	1.500	2.250	3.000	3.500	4.375	4.625	7.625	10.500	12	6.433
D-4	7.375															0.250	0.500	1.375	2.125	2.875	3.375	4.250	4.500	7.500	10.375	11	6.337
D-5	7.625																0.250	1.125	1.875	2.625	3.125	4.000	4.250	7.250	10.125	10	6.228
A-4	7.875																	0.875	1.625	2.375	2.875	3.750	4.000	7.000	9.875	9	6.105
C-4	8.750																		0.750	1.500	2.000	2.875	3.125	6.125	9.000	8	5.955
D-3	9.500																			0.750	1.250	2.125	2.375	5.375	8.250	7	5.791
A-3	10.250																				0.500	1.375	1.625	4.625	7.500	6	5.600
D-1	10.750																					0.875	1.125	4.125	7.000	5	5.354
C-3	11.625																						0.250	3.250	6.125	4	5.026
B-3	11.875																							3.000	5.875	3	4.589
C-2	14.875																								2.875	2	3.824
C-1	17.750																									1	

VITA

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