Gerontechnology® and
functional physical fitness specifications

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"Functional Assessments of the Physical Abilities in the Elderly"

and

the WHO-workshop "Quality of Life of Elderly People"
GERONTECHNOLOGY® AND FUNCTIONAL PHYSICAL FITNESS SPECIFICATIONS

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ABSTRACT

Gerontechnology includes the research and development of techniques and technological products, based on the knowledge of aging processes, for the benefit of an optimal living and working environment and adapted medical care for the elderly. Physical fitness is a prerequisite to the satisfactory performance of daily tasks. Functionality decreases when motor abilities or motor skills diminish, when task demands are too high and/or when the product characteristics, the user-interface or the environmental conditions are in conflict with human skills. In order to be able to define functional specifications for the technological environment of elderly people, a profound understanding of the changes and possible rehabilitation of their physical fitness is required. It is questioned which abilities and skills should be trained to prolong independence.

INTRODUCTION

The last chapter (126) of Principles of Geriatric Medicine and Gerontology is titled: Predicting Functional Outcome in Older People (Williams & Jones, 1990). In the first paragraph it is stated that the prediction of an older person’s abilities is a primary goal of geriatric care, because the level of function may indicate an older person’s ability to cope with a particular environment. Functional decrease forces a patient to adapt in one or more ways: accept the limitation; develop new strategies to overcome the disability; move to a less demanding environment; or increase reliance on support systems such as family, friends, health care workers, social agencies and nursing homes.

Although this book is of a recent date a few comments are in place on the opening statement of this chapter. First of all the statement is primarily based on a medical or care patient model and not on the creation of a more functional or matched environment. It is still a medical push instead of a client pull. The latter approach is used more and more often in human factors research or ergonomics, where the focus is on the adaptation of the task and the environment than on the provision of protection and help. Secondly, the possible solutions that can be created by technological innovations are not mentioned at all. It is obvious that not all problems can be solved with technology, but it might be worthwhile to seek solutions where new combinations of technical products with adapted care provisions can create independence, autonomy and comfort for the individual. A higher quality of life may be within reach, possibly even at a lower price. Matching the technological environment with the faculties and needs of the elderly is the main objective of the Gerontechnology programme as described in: Gerontechnology, Studies in Health Technology and Informatics, Vol. 3 (Bouma & Graafmans, eds., 1992).
In the interaction of a human being with the environment the options of perception, cognition and physical and motor action are determined by the abilities and skills of the individual person. The quality of the communication of the individual with the social as well as technical environment is also determined by the quality of the user-interface. Here, an increasing gap arises between the range of suitable products and services and the skills of the elderly. Bridging this gap is the main challenge for a fundamental and applied research programme in gerontechnology.

Independence as a quality of life in our society is desirable for every human being. Independence requires the capability of effectively solving daily problems. This capability relies not on human perception, cognition and locomotion alone. Most people supplement their skills or compensate for their disabilities and handicaps with products and tools that provide a larger range of possibilities in perception, information processing and/or mobility. Products are purchased to meet daily needs as effectively and efficiently as possible. Environmental conditions also determine whether or not the optimal interaction between man and product can be achieved. Theoretically an activity cannot be performed satisfactorily if one or more human functions are lacking or operate on too low a performance level. Performance depends upon the joint operation of four factors (Welford 1982):
- the demands made by the task
- the capacities, physical and mental, that the operator brings to the tasks
- strategies by which capacities are deployed to meet demands
- skill, i.e. the choice and use of efficient strategies.

It is known that every human function - physiological, psychological or social - changes with age. For quite a few functions this change means a decrease of performance. Needs for appropriate products will arise when the performance of a specific human function declines below a certain threshold. At the level where people encounter problems with ease of everyday activities they will be encouraged to purchase better, or more convenient consumer goods or services if available at reasonable prices. When passing the independence threshold, needs will be expressed for special health care, social support, adapted housing, aids for disabled, etc.

Therefore, it is necessary to carefully ascertain which faculties of elderly individuals are relevant and assess the distribution of these faculties in the population. Next we can try to define the critical values below which functioning in specific tasks becomes more difficult. This has to be done for as many faculties as seem relevant for normal daily life.

It is known that both physical and mental functions of elderly could profit from exercise. First of all, though, we need a better understanding of the normal physiological aging of perceptual, motor, cognitive and physical functions and secondly we should gain a better view of which functions are most responsive to training and which are less so.

The following paragraphs will highlight the aging of functions that determine the physical performance and the possible effects of exercise (cardio-respiratory system, muscle strength, endurance, flexibility, speed, coordination).

We have to keep in mind though, that the functional performance of the musculoskeletal system cannot be described without taking into account the
cognitive and perceptual performance and the socio-psychological characteristics of the older individual. It is also important to look into the methods that are used to collect the data on aging of functions. Both longitudinal and cross-sectional studies have their advantages and shortcomings. The final paragraph is an attempt to connect physical functions and exercise with activities of daily life and products that can support these activities.

METHODOLOGY IN RESEARCH ON AGE-RELATED CHANGES IN PHYSICAL PERFORMANCE

The human body is a very complex system with many subsystems. When studying physical performance, not only muscles, bones and joints, but also the cardio-vascular, respiratory and nervous system should be taken into account. For the purpose of this paper a model (Fig. 1) will be used that is derived from systems and control theory (Wijnands, 1993). The human body can be seen as a multi-body system (MBS) that has output variables like displacements, velocities, accelerations and forces. Activities of daily life can be seen as dynamic processes of the multi-body system. The actual state (Sa) of the proces is sensed by the perceptual system (P) as a perceived state (Sp) and compared with a desired state (Sd) in the cognitive system (C). Discrepancies between Sp and Sd will lead to corrective signals for the muscular system (M) which will change the Sa. In this model, the role of the cardio-respiratory system (CR) is to supply energy to the muscular system. Of course this model is oversimplified but it can serve the purpose of the description of age-related changes in physical performance. Although the scheme may suggest that we have a closed-loop system, this is not the case since for example environmental perturbations may influence perception and the multi-body system is in constant interaction with the environment (action = reaction and gravitation).

![Figure 1: The human body as a systems-model (Wijnands, 1993)](image-url)
When studying age-related changes in physical performance, different approaches are possible. One can choose for a longitudinal or a cross-sectional study or even mixed forms of these (Deeg, 1989) and at the same time it is possible to vary the research between microscopic details like speed of nerve conduction and macroscopic targets such as endurance. It is not always obvious which method is the most appropriate. In the cross-sectional approach the variables of chronological age and generation are confounded; in the longitudinal approach chronological age and environment (time of measurement) are confounded. Tables 1 and 2 compare the advantages and disadvantages of longitudinal and cross-sectional studies and detailed versus overall approaches.

<table>
<thead>
<tr>
<th>Cross-sectional</th>
<th>Longitudinal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fast results, useful for trend prediction</td>
<td>Slow start, no preliminary results</td>
</tr>
<tr>
<td>Only averages over subjects</td>
<td>Averages and individual changes</td>
</tr>
<tr>
<td>Cohort effects</td>
<td>Aging effects</td>
</tr>
<tr>
<td>No test effect</td>
<td>Learning effects and other positive influences</td>
</tr>
<tr>
<td>No drop-outs, only selective refusals</td>
<td>Drop-outs</td>
</tr>
<tr>
<td>Representative samples of subjects</td>
<td>Representativity might change over years</td>
</tr>
<tr>
<td>Measurements are independent</td>
<td>Systematic faults are repeated</td>
</tr>
<tr>
<td>Underestimation of changes due to survival of the fittest</td>
<td>Changes in the subject group due to mortality are observable</td>
</tr>
<tr>
<td>No historical data so no conclusions for the future</td>
<td>Expectations for the future are predictable</td>
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Table 1: Differences between cross-sectional and longitudinal studies (Deeg, 1989)

Both the analysis of the activities of daily life and of the related difficulties of the elderly and the results of more detailed studies require further interpretation as to what the implications are for interventions. The overall analysis has to be followed by a top-down unravelling of the major causes of problems. Results of more detailed studies have to be combined into bigger complexes in order to come closer to the reality of daily life (bottom-up).

<table>
<thead>
<tr>
<th>Top-down</th>
<th>Bottom-up</th>
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<tbody>
<tr>
<td>Ergonomical approach -&gt; Accepted rules of thumb</td>
<td>Exact approach, scientifically sound</td>
</tr>
<tr>
<td>Incorporates compensation mechanisms</td>
<td>A change does not always imply a problem</td>
</tr>
<tr>
<td>Diversity among the elderly (Average-fallacy)</td>
<td>Variables can be described more accurately</td>
</tr>
<tr>
<td>Standardization of ADL is difficult</td>
<td>Test procedures can be protocolled</td>
</tr>
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Table 2: Comparison of levels of complexity in studying age-related changes (Wijnands, 1993)
Advancing age is accompanied by progressive decline in the functional capacity of multiple organ systems. The more prominent declines are the cardiorespiratory performance (Heath 1981, Fleg 1988), the loss of muscle and bone mass (Riggs 1986, Fleg 1988). Glucose and lipid homeostasis deteriorate. The variability among individuals can be attributed in part to genetic differences, but diseases and an individual's physical conditioning also play a role. Immobilization or even short periods of physical inactivity effect numerous physiological changes, that parallel the changes due to the aging process. In the Baltimore Longitudinal Study of Aging (BLSA) it was shown that caloric expenditure for physical activity decreased progressively with age (Fig. 2). On the other hand the elderly participate less in sports so the decline might in part be due to age-associated decline in activity rather than to aging per se.

![Graph showing the effect of age on the average daily caloric expenditure for physical activity in volunteers from the BLSA (McGandy, 1966).](image)

Several important issues need to be discussed when studying the interactions between physical conditioning status and the physiological changes which often come with the aging process:
- Can older sedentary individuals be physically trained?
- To what extent can or should they be trained?
- Is there a relation between regular exercise and the aging of the cardiovascular system?
- Is there a relation between glucose homeostasis, lipid metabolism, bone density?
- Does exercise decrease morbidity and mortality from cardiovascular disease?
- Is maximal aerobic capacity or VO\textsubscript{2max} a good index for physical fitness of the elderly?

Maximal aerobic capacity in the elderly.
In the exercise sciences literature, physical fitness is generally defined as the maximum level of physical work of which an individual is capable. Physical work capacity is reported in terms of maximal oxygen consumption (VO\textsubscript{2max}).
This represents the maximal ability of the cardiovascular system to deliver oxygenated blood to the periphery and the capacity for exercising muscle and other tissues to extract oxygen from the blood. One of the most consistent findings is the age-related decline in VO\textsubscript{2max} at an average of 5-10% per decade (Fig. 3).

This decline is not caused by a decrease in the metabolic efficiency (walking goes less efficient in older age) nor is it a consequence of a decreasing maximal cardiac output as was universally believed until recently. The principal reason for the reduction of aerobic power with age is unknown. Rodeheffer (1984) showed that volunteers in the BLSA had only a slight, statistically non-significant, decrease in cardiac output with age during maximal exertion on a bicycle. Therefore, the earlier observed decreases in cardiac output might be due to unrecognized coronary artery disease. A further observation was that aerobic capacity per kilogram of lean body mass did not change appreciably with age, which indicates that the loss of muscle tissue is important in the decline of aerobic capacity.

Most of the data however, are collected from studies with trained subjects who had and still have an active sports life. Since this is not the case for the average elderly a more pragmatic question is: Can sedentary older men and women derive a significant training effect from an aerobic exercise program? Until the past decade it was believed that healthy individuals older than 60 could not increase their VO\textsubscript{2max} as a result from an endurance exercise training stimulus. Recent investigations show differently (fig. 4). There was also a significant improvement in pulmonary function with training (Yerg 1985) maybe due to improved gas exchange, although pulmonary functions were probably not a limiting factor for VO\textsubscript{2max} at baseline. The increase in VO\textsubscript{2max} resulted from exercise at lower work intensities (40% of VO\textsubscript{2max}). Other physiological variables such as body weight, body composition, percent body fat, plasma blood lipids, glucose tolerance and insulin sensitivity, did not seem to improve until the elderly trained at higher work intensities (Seals 1984). The aging cardiovascular and neuromuscular systems respond well to aerobic training. The aerobic capacity and enzymatic metabolism of aged muscle increase with training to
similar extents by essentially the same mechanisms as those identified in young muscles (Örlander & Aniansson, 1980).

![Graph showing changes in VO2 max resulting from aerobic exercise training programs in subjects older than 60. In general, the lower the initial fitness level, the greater the improvement with training (Adapted from Badenhop 1983 in Fleg 1990).](image)

Muscle structure and function with aging. Many tasks in everyday life, such as lifting, pushing or pulling involve primarily isometric or static exercise. In contrast to aerobic exercise these isometric activities are mostly anaerobic and are measured as strength. A number of studies have reported age-related loss of maximal isometric strength. Above the age of 30 this loss averages about 40% in the leg and back muscles and about 30% in the arm muscles over a period of 50 years (Asmussen 1980). Leg and back muscles are used less frequently than arm muscles in the daily activities of older people. This might cause the faster decline. However, a steeper decline has been reported in muscles used very frequently, and lower strength has been seen in old men who previously did manual work as compared to those with a former sedentary occupation (Aniansson, 1980).

Both isometric and dynamic strength decrease with age, particularly beyond age 50 (Larson, 1979). Performance is largely limited by the aerobic power of the subject. In contrast, when measuring the ability to maintain tension output during isometric or dynamic contractions for a short time period, the influence of the cardiovascular functions is minimized while the endurance capacity of the muscle tissue itself is limiting. Loss of strength originates mainly from loss of
muscle fiber and not from decrease of muscle fiber size. There is also a decline in the number of functioning motor units parallel to a loss of motor neurons in the nervous system. The remaining motor units appear to enlarge so that they might include more muscle fibers. Several studies suggest that ‘aged muscle’ can increase in strength after a training stimulus. Frontera (1988) found big increases in both strength and muscle areas in men 60-72 years old, after a 12-week program of strength training, thus showing that skeletal muscles can be trained with isometric stimuli even in old age. Such training has the potential of enhancing the daily functional capacity of elderly, since many activities of daily living (climbing stairs, rising from a chair or toilet) depend on muscular strength.

**STABILIZATION OF AGING MOTOR FUNCTIONS**

Although the variability in the motor function among elderly is great, some changes are found with such regularity that they can be attributed to normal aging of the motor system. These many different factors might contribute to age-related decrease of motor performance. Among the prominent changes are:
- Declines in neuronal density (a.o. in the cerebellum), regression of dendrites, loss of synapses. Due to plasticity this degeneration might cause effects only in very old age (Curcio 1982)
- Relative and absolute decline of fast twitch muscle fibers (type II) and associated motor neurons affecting both peak muscle strength and speed of contraction (Larsson 1979)
- Sensory changes like decline of visual acuity and stereopsis that could limit motor performance in more complex visuo-motor tasks (Corso 1992)
- Disturbances in the temporal organization of motor synergies mediated by the long latency postural reflex system causing higher risks of falls especially during unstable support conditions (Nashner 1979)
- Decline in dopaminergic function in the basal ganglia resulting in slowed motor function in tasks where maximum speed is required (Potvin 1980)
- Decrease in the maximum rate of sequential repetitive movements (Welford 1982)
- Performance deficits in tasks in which complex programming or transformations are required (Welford 1982).

On the other hand a number of functions are preserved into very old age and some changes may not ever become apparent during the normal life span. Some well-preserved functions are:
- The morphological integrity of several central nervous system structures related to motor function (Curcio 1982)
- Endurance capacity if corrected for muscular strength (Larsson 1979)
- Monosynaptic reflex function (Spirduso 1981)
- Skilled performance under situations where task demands do not exceed maximal task performance (Welford 1982)

Some effects of physical training, behavioral therapy, or medication might be expected when the intervention programme is directed towards the factors that show age-related decreases. At the same time it should be considered unnecessary to design interventions aimed at the optimization of functions
which are considered to be well preserved into very old age. Finally, a paramount challenge remains for ergonomists, designers and engineers, since the ultimate approach will always be to fit the tasks, the products, their user-interfaces and the environment to human beings and not vice versa. This will be discussed in the next paragraph along a theoretical scheme that has been set up for this purpose.

DISCUSSION

When discussing specifications for a program aimed at the maintenance of functional physical fitness at least four focus questions require an answer:
- Which important changes of capacities are related to age
- Can these changes be minimized or even reversed
- Are changes in strategies a solution for matching human capacities to task demands
- What are the possible effects?

The lines in figure 5 show the relation between maximal task performance (T<sub>p</sub>) and task demand (T<sub>d</sub>, solid line) during human life. Comfort can be defined as the result of T<sub>p</sub>-T<sub>d</sub> and Dependency as the result of T<sub>d</sub>-T<sub>p</sub>. The scheme suggests that children are dependent during their learning period which is generally accepted. The scheme also shows that the elderly are at a higher risk of becoming dependent with increasing age because their surplus of comfort is getting smaller. This means that, when they are suddenly confronted with a high task demand (like driving on a dark rainy night in an unknown area), or experience an unexpected drop in maximum task performance (like a sharp decrease in aerobic capacity due to a pollen allergy) a temporarily total or partial impairment might occur.

![Fig. 5: Relation between task performance, task demand, comfort and dependence during human life.](image)

These situations can be prevented. A negative approach is avoidance of risk situations, probably leading to disengagement and lower levels of activity.
Consequently, maximal task performance will decrease more rapidly. A positive approach might be to exercise in such a way that maximal task performance for most activities of daily life is kept at a sufficient level (mind and body jogging). One example is given in this article. The physiological decrease of aerobic capacity can be postponed with one decade if a certain level of daily physical exercise is maintained. The intensity and duration of the exercises is not necessarily high. An even better approach is trying to prevent a sudden rise in task demands. In the given example this means better road signs, protection of the eyes against glare, prophylactic medication, etc.

In conclusion one might state that a good understanding of the interplay between task demand and task performance can nourish engineers and designers with the type of information that is needed to create a functional environment, comfortable for the elderly and even more so for all.

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