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CHAPTER 7

General discussion and conclusions

The word of man is the most durable of all material.

Arthur Schopenhauer
7.1 Main conclusions and insights

In this chapter we summarize the main findings and conclusions, in regard to the different phases of treatment delivery addressed in this thesis, and propose directions for further development. Next, the rationale for a comprehensive framework for technological innovation in SLT are presented, and a functional model of that framework is outlined.

Summary of contributions

The work presented in this thesis contributes to the field of speech-language therapy through the demonstration of specific methodological refinements applied to three central phases of treatment delivery. First, a methodological shift has been proposed for the preparation of treatment programs — from the traditional usage of rather static inventories of speech items — towards providing clinicians with the means for compiling individually customized treatment targets and exercises. Chapters 3 and 4 presented two complementary steps on the way to realizing this refinement — the obtaining of linguistic materials needed for generating parametrized speech targets, and the design of an appropriate computer-interface for clinicians, allowing to perform the generation. The results of Chapter 4 confirm the assumption that speech clinicians, in general, recognize the added value of being able to compile customized treatment targets for their patients, as well as the efficiency and flexibility offered by the computer application designed for that purpose.

Next, a methodology has been proposed for practicing timing skills in speech with a computer game. Although voice-based computer games in speech-language therapy are not new, and several systems for practicing timing skills in the motor domain exist, the prospect of training timing skills with speech input has not yet been examined. The investigation presented in Chapter 5 contributes to the understanding of the elements necessary for constructing a training application for timing skills in the speech domain.

Finally, an improvement of the current methodologies of altered auditory feedback (AAF) for people who stutter is proposed and tested. Chapter 6 examined the utility of adaptive feedback procedures, which are based on real-time analysis of the speech signal and the dynamic activation of auditory cues, as opposed to the static feedback function utilized in current AAF methods. The results of this work provide valuable insights for future attempts of taking forward the methods for enhancing the speech fluency of individuals who stutter. Next, we discuss possible future directions in the work presented in this thesis.
Generation of speech treatment materials

In order to enable a systematic selection of treatment targets, databases of linguistic material are necessary, which are annotated with clinically relevant parameters. In Chapter 3, spoken and canonical syllabic inventories of Dutch were obtained by means of automatic syllabification of spoken language data, and the consistency of both syllabic inventories was examined, providing insights on their applicability as speech training materials. The obtained syllabic inventories may, in turn, be used to address ongoing psycholinguistic inquires. For example, by examining the way spoken syllable frequencies interact with the frequencies of the sub-syllabic parts (demisyllables, onsets, and rhymes), and with the frequencies of bi-syllabic patterns, new insights can be sought about the internal organization of the mental syllabary, and the role of syllables in speech production. Enabling clinical researchers to perform an elaborate parameterization of linguistic materials in their studies may facilitate the investigation of finer-grain phenomena in pathological speech production. Enabling clinicians to include and structure these materials in their treatment programs may facilitate the delivery of treatment based on current theoretical knowledge.

In Chapter 4, a computer application has been described, designed to provide a flexible, efficient, and intuitive workflow. A usability study with the application has echoed highly positive responses, and clinicians regarded the program as a useful, time saving tool for the creation of treatment programs. A natural evolution in this direction will be linking the various functions involved in the preparation of speech treatment programs into one coherent computer application, which will facilitate a structured workflow, hinged on best-practice evidence from the clinical literature. Besides promoting a systematic delivery of treatment, a computer application can be designed to access different databases of linguistic materials, which can be easily extended and updated (for example, a web-based implementation would ensure such flexibility). Finally, it is likely that all the different procedures involved in preparing treatment programs for MSD patients will eventually be integrated into one coherent computer application for the management of treatment protocols. Furthermore, mobile devices may gradually replace paper-based protocols used for presenting speech targets to patients during practice, as well as for the entering of results by the clinician.

Computer games for the training of speech motor skills

In Chapter 5, the use of a computer game for practicing speech timing skills of children with MSD was examined through a usability study. The results of the investigation presented in this thesis suggest that interactive games for practicing speech timing skills can promote a positive experience of speech motor training and enhance motivation for practice, at least in the short term. The interaction with the game added to the training situation, and was appreciated by children. Naturally, children have high demands on quality and entertain-
ment values of the computer games they play, and these demands remain valid also in speech training situations. Consequently, there is a significant risk that custom-made games will not be able to compete with entertainment-oriented commercial games. One possible way to address this challenge is by retrofitting existing games, so that they can be interfaced with audio input. For open-source computer games, audio processing can be directly integrated within the game’s code, producing an audio-based variant of that game. For example, for supporting the training of speech timing skills discussed in this thesis, the following two games could be considered (See Figure 7.1). In both cases, since progress within the game is determined by the timing of input gestures, syllable detection events could be mapped to the dynamics of the game.

![Image](image1.png)

**Figure 7.1:** Tux Racer (left) is an open-source downhill racing game, where the player controls Tux (the Linux mascot) as he slides down a course of snow, collecting herring. Frets on Fire (right) is an open-source music video game that imitates the commercial game Guitar Hero. The game is normally played by using a keyboard, pressing the fret and pick buttons.

The immediate advantage of this approach is in opening up a large variety of potentially effective synergies between available computer games, and the desired training effect throughout the gaming activity. The large selection of different games and interaction modes should provide opportunities to choose and match games according to the specific exercise goals and skills to be trained. Furthermore, utilizing popular computer and video games for therapy purposes is likely to decrease the risk that gaming will be perceived as tedious, compared to custom-made games (Sandlund et al., 2009a).

However, a number of potential caveats in this direction must be mentioned. First, available games may not be able to provide as specialized training as would games designed particularly for a certain practice methodology. Second, the mapping between acoustic parameters to action commands native to a certain game may not be intuitive, and designers may need to re-map these parameters for different games.
Demonstrating clinical e ectiveness of computer game training methods in speech therapy with children involves an obvious di culty. Exercises performed with a computer game only constitute a fraction of the whole range of treatment activities, regardless of the disorder being treated. Therefore, it is rarely possible to isolate the e ects of this form of training on speech performance, from the e ects of other treatment activities, the deferral of which is not realistic from a clinical perspective (Onslow et al., 1994).

Refinement of fluency enhancing procedures

Altered Auditory Feedback (AAF) devices grow smaller and more inconspicuous with the years. However, the underlying feedback procedures remain unchanged, characterized by a significant limitation of not taking into account the ‘state’ of the speaker at any given moment. A possible refinement examined in this thesis is the design of adaptive AAF procedures. Future e orts in advancing AAF methodologies should take advantage of techniques and theories from other related fields. For example, the ‘synchronous reading’ task (a situation when two people read the same text simultaneously – a fluency enhancing condition known as ‘choral speech’) has been thoroughly investigated with fluent speakers, by Cummins (2009). Integrating knowledge from similar experiments is likely to promote better theoretical understanding of the underlying processes of fluency modulation in individuals who stutter.

Although most participants in our study were aware of the existence of AAF devices, none had a prolonged positive experience with such a device. This situation might indicate that current AAF methodologies may not be optimally developed. As long as AAF methodologies will not include intelligent procedures to customize and adapt settings to individuals, it is not likely that their potential benefits to people who stutter will be fully realized. The design of adaptive feedback procedures involves a large space of possible configurations in terms of input signal analysis, selection of auditory cues for output, and the mapping function between input and output. Since the adaptive procedure examined in this work has lead to a fluency enhancement comparable with current AAF methods, we believe that this line of development will contribute to future e orts to innovate fluency-enhancing techniques. Support for this notion comes directly from participants in our study, the majority of whom have expressed positive attitudes towards these e orts. We quote one of the participants:

"Ik denk wel dat er op een gegeven moment manieren komen waarop je elke vorm van spraak zo kan sturen dat hij vloeiend gaat lopen, dat er wel middelen voor te maken moeten zijn."

"I believe that at some point methods will be available with which every form of speech could be directed towards fluent speech, that tools for this purpose will be developed."
7.2 A durable development framework

Challenges in technological innovation for SLT

A central question concerning innovation efforts in the field of communication disorders is who, and within which framework, will initiate and carry out this kind of work. In principle, this can happen in two possible ways. First, clinicians may identify a potential for improving a certain methodology they use, and seek partners to provide the solution. Second, a group of researchers who develop a certain technology may wish to apply their techniques to a real-world problem, and seek clinical partners to identify a speech-language treatment methodology as an appropriate application domain.

In reality, although both workflows exist, their cumulative productivity does not, as it seems, reach a stable inertia of innovation in the field. A number of reasons can be put forward. First, due to the fact that SLT education curricula usually do not include experience with technological topics, the majority of clinicians do not promote innovative ideas involving technological concepts. As a consequence, partly due to lack of awareness of technological possibilities, there is, generally, little pro-active development initiation from the side of communication disorders specialists.

On the other hand, students and researchers at technical departments seldom choose to apply their skills to the field of communication disorders. Surely, there are exceptions, often driven by a personal experience, or interest. The resulting situation is that innovation efforts in the field occur rather sporadically, with few dedicated research and development structures to advance these efforts. This stands in stark contrast to other fields of assistive technology, for which ongoing research activities are organized within special interest groups, laboratories and specialized centers (Pino et al., 2010; Bates et al., 2007).

Towards a dedicated framework

The experience gained with development projects described in this thesis converges to the conclusion that a dedicated framework is needed in order to promote a durable process of innovation in the field of communication disorders. Such a framework would consist of ongoing collaborative research and development activities, involving university departments, and eventually industrial partners. Recently, more researchers recognize the need in an overarching framework for advancing innovation in the field of SLT. Cucchiarini et al. (2008) provide examples of successful previous efforts to organize a durable framework for the development of language technologies in the Netherlands, and propose mechanisms for the establishment of a comprehensive stimulation program for utilizing these technologies for the support of speech language therapy (Ruiter et al., 2010), supported by government, industry and academia.
In order to further contribute to these efforts, we propose a functional model of a dedicated framework for innovation in the field of SLT. The eventual aim of such framework is to enable a perpetual generation of innovative solutions, from which therapists can pool resources and capabilities for advancing novel technology supported therapies. The purpose of the model is to define the participating actors, and outline the main activities, interactions, and workflow within the framework.

A model of innovation in the field of SLT

First, the main actors participating in the framework are identified as follows:

SLT department A university department where speech language therapists are educated and trained. Ideally, the department is oriented towards research, and maintains ongoing collaborations with clinical institutions.

Partner departments A number of university departments where the realization of proposed solutions takes place. These will be computer-science, engineering, or other technical departments, as well as groups dealing with graphical design, interaction design, film and new media.

GISLT A team which consists of experts from both SLT and partner departments, whose roles are to lead the coordination between the involved disciplines. The team member’s role is twofold: they act as supervisors to student projects from their respective department, and they are responsible for the selection, analysis and design of the initiated projects. In order to refer to this team in a consistent manner, we shall term it – Group for Innovation in Speech Language Therapy (GISLT).

Next, the workflow is described, which outlines the basic interactions between the participating actors, and their respective roles in the framework (see Figure 7.2). The model consists of the following steps:

Innovation in SLT course. At the heart of the model is the educational course for speech language therapy students, which aims at generating innovative concepts and solutions for real-life problems and identified improvement potentials in this clinical field. A short description of the course, it’s goals and methods is given in Appendix B.

Project selection. The course for SLT generates a number of concepts and project proposals for innovation in the field. These proposals are evaluated for their potential impact and feasibility, so that a limited number of projects are selected for realization. For each selected project, the requirements are further specified and the design is elaborated in preparation for the development phase. These activities are carried out by the GISLT.
7.2. A durable development framework

**Figure 7.2: An outline of the innovation in SLT model**

**Initial development.** Selected projects are defined and offered to students as a graduation/thesis project, within an appropriate university department (which commits to an ongoing collaboration with the GISLT), where the required expertise, in relation to the defined problem, exists. Members of the GISLT are appointed as co-supervisors for these projects. The goal of this phase is producing a working prototype of the proposed solution, with sufficient documentation to allow subsequent phases of development.

**Initial testing.** The developed prototype is then evaluated in an initial usability study. The study is likewise defined as a graduation project within the SLT department, co-supervised by the GISLT. The study aims at gathering performance and usability data from real clinical experiences with the proposed solution by the target user group.

**Analysis and re-design.** The data collected from initial testing is analyzed and the feasibility of the proposed solution is re-evaluated by the GISLT. In case of positive outcomes, further refinements to the design are made, based on the collected data, and a further development phase is defined.

**Further development.** The refined specifications form the basis for another student project, possibly within the same department where the initial
development took place. The goal of this phase is producing a more mature realization of the solution, eventually including the human-computer interface for allowing a long-term deployment by non-experts.

Effectiveness testing. The potential clinical impact of the proposed solution is evaluated through an effectiveness study with the developed application. Defined as a group project within the SLT department, the study is carried out in collaboration with clinical partners, and aims at examining evidence for the effects of utilizing the proposed solution in clinical procedures.

Evaluation and deployment. In the case that effectiveness testing produces positive outcomes, the GISLT takes further steps towards integrating the developed solutions into the field. If further refinements are indicated, an additional cycle of development may be defined. Eventually, mature products can be distributed within the clinical field, or commercialized through the university's spin-off facilities.

The proposed model entails a number of potential advantages in relation to the current, sporadic way of advancing technological innovation for SLT:

» The initiation and the drive for creating innovative solutions comes from the clinical field (through the participation of SLT students in the practical part of the SLT course).

» The framework may promote the application of a wealth of technological knowledge resources, residing in technical departments, to real-life problems, as well as promoting awareness of assistive technologies among researchers in these departments.

» The framework may facilitate the commitment of speech clinicians to participate in long-term clinical studies.

» Since most of the activities throughout the model are performed within graduate student projects, innovation efforts are not heavily constrained by market size. The commercialization of eventual products is an option, but not a precondition for the research and development agenda.
7.3 Final remarks

The work presented in this thesis aimed to operate as the missing link between the needs of the clinical field of speech-language therapy, and a pool of existing techniques from technological domains (indications for that missing link originated in communication with different speech clinicians, who confirmed that efforts are needed to bridge this gap). A successful aspect of that role can be seen in demonstrating that a variety of clinical procedures can be supported through technological innovation, once attention is given to identified problems. However, the work process has also revealed significant structural challenges in the efforts to coordinate technological development in the field. The interpretation of these challenges suggested a need for a comprehensive, durable framework, and has led to the proposal of a model for technological innovation for SLT, described in 7.2.

Particularly, the model extends the workflow carried out within this thesis (as outlined in 1.3) in two important ways. First, the identification of problems and needs, as well as the generation of innovative concepts is placed within the field of SLT itself. This strategy ensures that the Analysis Phase is performed with the strongest involvement of clinicians, so that most relevant problems in the field are addressed. Second, established collaborations within the model should ensure that multiple iterations of development and testing can be carried out, on the way to mature clinical tools.

Finally, with all due respect to the potentials of technological innovation for supporting the procedures of speech-language therapy, it is good to redraw the realistic proportions of their role. In spite of the fact that technology-based methods have been the focus of this thesis, we must remind that in the very central role in the delivery of treatment always stands the speech therapist, and the role of technological support is complementary. After all, to be able to assist people with communication disorders, a kind of sympathetic sensitivity is required, which is uniquely human.