Morphosyntactic Production in Stroke-induced Agrammatic Aphasia: A Cross-linguistic Machine Learning Approach (Machine Learning Aphasia)

1. Relevance relative to the call for proposals

Each year 1.1 million people in Europe experience their first stroke (Truelsen et al., 2005), and, as a result of their stroke, approximately 360,000 Europeans experience *aphasia*, which is "the loss or impairment of language caused by brain damage" (Benson, 1979, p. 5). Aphasia has devastating effects on the affected person and the society at large for a number of reasons. It compromises communication, and given that communication is a fundamental self-defining activity, it directly affects one's sense of identity (Parr et al., 1997). The resulting isolation from family and community (Cruice et al., 2006) has a negative impact on the emotional well-being of persons with aphasia (Cruice et al., 2003). Aphasia is also related to poorer activities of daily living, mobility (Paolucci et al., 2005), and return to work (Black-Schaffer & Osberg, 1990). It is estimated that stroke treatment and rehabilitation in Europe costs €2.2 billion each year (Andlin-Sobocki et al., 2005), and there is evidence that aphasia "adds to the cost of stroke-related care, above the cost of stroke alone" (Ellis et al., 2012, p. 1429). Based on increased stroke survival rates and on the ageing of the European population, it is safe to estimate that the incidence of aphasia and the cost of stroke and aphasia treatment and rehabilitation will increase further (Collaboration of Aphasia Trialists, 2013). Therefore, effective management and rehabilitation of aphasia is vital.

An effective treatment, however, is not possible without **a thorough knowledge of the manifestations of aphasia in different languages**, and without a **deep understanding of the nature** and of **the underlying causes of the disorder**. Besides obvious clinical implications, **such knowledge can also inform linguistic and cognitive theory**, as several hypotheses proposed to account for patterns of impairment in aphasia are inspired by theoretical constructs and models in (psycho)linguistics and cognitive psychology.

The aim of the proposed project is to **improve state-of-the-art knowledge on aphasia**, focusing on **verb-related (morpho)syntactic production**. This deficit is considered to be the hallmark of ***agrammatic aphasia***, which usually occurs following damage to Broca's area and neighbouring areas in the left hemisphere. Although many studies on (morpho)syntactic production in agrammatic aphasia have been conducted thus far, **little is known on the factors that determine the relative preservation or impairment of a given verb-related morphosyntactic category** (e.g., Tense, subject-verb Agreement, grammatical Mood) **in a given person with agrammatic aphasia (PWAA) in a given language** (see section 2). Inspired by the developments in **machine learning**, the proposed project aims at filling this gap by taking an **original and innovative methodological approach**. *Machine Learning Aphasia* addresses two important, yet unanswered questions: (1) **Which factors determine the performance accuracy of a given PWAA, native speaker of a given language, on verb-related morphosyntactic production?** (2) **What is the hierarchy of factors/predictors of successful verb-related morphosyntactic production in agrammatic aphasia?** The proposed study will advance our understanding of the complexities underlying morphosyntactic production in agrammatic aphasia, thus **significantly contributing to cognitive science**. The project will also have **significant clinical implications**. *Machine Learning Aphasia* is **multidisciplinary** as it draws on expertise in theoretical linguistics, psycho-/neurolinguistics, cognitive (neuro)psychology, machine learning, and speech language pathology.

2. Aspects related to the research project

2.1 Background and status of knowledge

The proposed project focuses on **stroke-induced aphasia**, and in particular on ***agrammatic*** **aphasia**. As mentioned above, different domains and modalities of language can be affected in aphasia. For example, people with aphasia can be impaired in lexicon and/or (morpho)syntax in production and/or comprehension. **The hallmark of agrammatic aphasia is impaired verb-related (morpho)syntactic production**, which is often selective (e.g., Friedmann & Grodzinsky, 1997; Fyndanis et al., 2012). Interestingly, *dissociations* (i.e. significant differences in the performance) have been reported not only between morphosyntactic categories (e.g., Tense more impaired than subject-verb Agreement; op. cit.), but also within morphosyntactic categories. For example, Time Reference, which is closely related to Tense, has been found to be selectively impaired, with reference to the past being more impaired than reference to the present or to the future (see Bastiaanse, 2013, and references therein). Importantly, recent evidence suggests that the **impairment in morphosyntactic production is exacerbated by Working Memory (WM) limitations** (e.g., Kok et al., 2007), which are also frequent in aphasia, **or results from such limitations** (Fyndanis et al., 2018b). (WM is the memory system that is responsible for storing and processing items for a short period of time.)

Several accounts of the (morpho)syntactic impairment in agrammatic aphasia have been proposed. They are divided into representation and processing ones. Representation accounts posit total or partial loss of (morpho)syntactic "knowledge". Processing accounts argue that (morpho)syntactic knowledge is preserved, but access to or implementation of such knowledge is impaired. It should be noted that both representational and processing accounts borrowed notions and "descriptive tools" developed within the Generative Grammar framework (e.g., Chomsky, 1995, 2000). Importantly, most representation and processing accounts constitute **unitary accounts of the (morpho)syntactic impairment** in agrammatic aphasia, that is, accounts focusing on one factor only.

For example, Hagiwara (1995) and Friedmann and Grodzinsky (1997) focused on the **position of a given morphosyntactic (*functional*) category in the syntactic hierarchy**. However, they provided contrasting accounts of the role that this factor plays in agrammatic production. Hagiwara (1995) argued for a processing account: morphosyntactic/functional categories higher in the syntactic hierarchy are more impaired because, for a higher node to be projected, the syntactic process of *Merge* has to be applied more times, which taxes WM. Friedmann and Grodzinsky (1997) put forward the *Tree Pruning Hypothesis*, which has been a very influential representational account. According to this hypothesis, the syntactic tree is "pruned" at a node, usually Tense. Consequently, nodes below the pruning site are preserved, but all nodes above the pruning site are inaccessible.

Fyndanis et al. (2012) proposed a processing account that employed the notion of **integration processes**. This account posits that categories bearing interpretable features (e.g., Tense/Time Reference, Aspect) are more difficult to process than categories bearing uninterpretable features (e.g., subject-verb Agreement), because they require processing and **integration** of information from two distinct levels of representation (i.e. extralinguistic/conceptual and grammatical). In contrast, categories bearing uninterpretable features require processing of grammatical information only; thus, they do not involve integration. PWAA are known to have limited processing resources. Thus, they are more impaired in producing morphosyntactic categories that involve integration processes than categories that do not involve integration. This account will be henceforth referred to as the *original Interpretable Features' Impairment Hypothesis*.

Within the spirit of the Distributed Morphology framework (e.g., Harley & Noyer, 1999), Wang et al. (2014) formulated the *Distributed Morphology Hypothesis*, which is a representation account of morphosyntactic impairment in agrammatic aphasia. On this account, morphological insertion processes, not syntax, are genuinely affected in agrammatic aphasia, and all categories involving **inflectional alternations** (e.g., Tense: walk–walk*ed*) should be comparably impaired.

Recently, Fyndanis et al. (2018c) updated the original Interpretable Features' Impairment Hypothesis (Fyndanis et al., 2012). The *revised Interpretable Features' Impairment Hypothesis* states that only categories involving **both integration processes and inflectional alternations** are impaired in people with limited processing resources, such as PWAA or individuals with Alzheimer's disease.

To account for the within-Time Reference dissociation (i.e. past reference < present/future reference) observed in several languages (Bastiaanse, 2013, and references therein), Bastiaanse et al. (2011) formulated the Past Discourse Linking Hypothesis, which is a processing account. This hypothesis posits that past reference through verb inflection is selectively impaired in agrammatic aphasia because, unlike present and future reference, it involves **discourse linking** (Zagona, 2013).

Although all the hypotheses above are expected to hold cross-linguistically, **evidence argues against their cross-linguistic validity** (for evidence against the Tree Pruning Hypothesis, see Fyndanis et al., 2012, and references therein; for evidence against the Past Discourse Linking Hypothesis, see Fyndanis et al., 2018a; for evidence against the Distributed Morphology Hypothesis and the two versions of the Interprerable Features' Impairment Hypothesis, see Fyndanis et al., 2017b; in prep.). Hence, recent findings as well as findings of earlier studies on agrammatic aphasia (e.g., Miceli et al., 1989) suggest that **no unitary account of agrammatic morphosyntactic production can succeed**. Nevertheless, although the unitary accounts above do not have cross-linguistic validity, the factors each of them emphasizes may still affect morphosyntactic production to some extent. It is possible that **a number of category-specific, subject-specific, task-specific and material-specific factors interact in determining the level of performance of a given PWAA on a given morphosyntactic category in a given language**. Category-specific factors may include the involvement of integration and inflectional processes, as well as the position of a given morphosyntactic category in the syntactic hierarchy, among other factors. Subject-specific factors may involve WM capacity, processing speed, severity of aphasia/agrammatism, education, and lesion site and volume, among other factors. Task-specific factors may involve the mode of stimulus presentation (oral, written, or cross-modal) and of response (oral or written), among other factors. Material-specific factors may involve frequency, imageability, length, and age of acquisition of the target verb forms, among other factors.

Paving the way for the proposed project: Preliminary data

To explore which factors affect verb-related morphosyntactic production in agrammatic aphasia, Fyndanis et al. (in prep.) collapsed the datasets of 26 Greek-, German-, and Italian-speaking PWAA and employed machine learning algorithms to analyse the data. **Machine learning algorithms can handle unbalanced designs and complex interactions better than mixed-effect modes**. Moreover, **they can also extract variable importance**, that is, they can identify the factors that influence the performance on the dependent measure/variable, and also rank these factors as for their importance/magnitude of contribution (Tagliamonte & Baayen, 2012; Hastie et al., 2009). Therefore, **employing machine learning algorithms can help us generate solid knowledge about the hierarchy of factors that play a role in morphosyntactic production in agrammatic aphasia**. Motivated by the literature on aphasia and cognitive psychology, Fyndanis et al. (in prep.) included 14 relevant subject-specific, category-specific and task-specific predictors: *Verbal WM capacity*, *Years of formal education*, *Age*, *Gender*, *Mean Length of Utterance in (semi)spontaneous speech* (Index 1 of severity of agrammatism), *Proportion of Grammatical Sentences in (semi)spontaneous speech* (Index 2 of severity of agrammatism), *Words per Minute in (semi)spontaneous speech* (Index of fluency), *Involvement of integration processes*, *Involvement of inflectional alternations*, *Involvement of both integration processes and inflectional alternations*, *Position of a given morphosyntactic category in the syntactic hierarchy of its language*, *Item Presentation mode*, *Response mode*, and *Language*. Different machine learning algorithms were employed (i.e. Random Forests, C5.0 decision trees, RPart, and Support Vector Machines) and the highest accuracy (0.786) was achieved by Random Forest. Recent studies (e.g, De Aguiar et al., 2016; Arslan et al., 2017) have successfully employed Random Forest algorithms to analyse aphasia datasets. Fyndanis et al.'s results suggest that the best predictors of accuracy on tasks tapping morphosyntactic production are the involvement of both integration processes and inflectional alternations, verbal WM capacity, and severity of agrammatism. These results are consistent with the revised Interpretable Features' Impairment Hypothesis (Fyndanis et al., 2018c) and with recent findings highlighting the role of verbal WM in morphosyntactic production (e.g., Fyndanis et al., 2018b; Kok et al., 2007).

However, although this approach to morphosyntactic production in agrammatic aphasia is original and innovative, Fyndanis et al.'s study is only the first step, because it relied on a relatively small dataset (4,598 data points). Thus, the best performing machine learning model reported in Fyndanis et al. (prep.) is likely to perform poorly on new and unknown data, meaning that the evidence it reports is far from conclusive. **Machine learning models require a lot of data for training and evaluation** (Hastie et al., 2009), especially when there is a lot of within- and between-subject variance, as is often the case with agrammatic aphasia. Therefore, **our current database** (which underlies Fyndanis et al.'s study) **should be expanded by including data from more PWAA, and ideally from more languages**. Employing advanced machine learning algorithms to analyse sufficiently large datasets will allow us to obtain more reliable results, which will be reflected in the accuracy, specificity, and sensitivity of the best model.

Goal of the proposed project

The goal of the proposed project is two-fold:

(1) to **investigate which factors play a role in determining the level of performance (accuracy) of a given PWAA on a given verb-related morphosyntactic category in a given language**.
(2) to **find out what is the hierarchy of predictors of successful verb-related morphosyntactic production**.

Addressing questions 1 and 2 will advance our understanding of the complexities underlying morphosyntactic production in agrammatic aphasia, which will be a **significant contribution to cognitive science** (in particular to psycholinguistics, neurolinguistics, theoretical linguistics, and cognitive neuropsychology). Importantly, achieving goals 1 and 2 will also have **significant clinical implications**, as the findings about the best predictors of morphosyntactic production in agrammatic aphasia will inform and improve treatment programmes for PWAA. For instance, if the proposed study finds that verbal WM capacity is one of the best predictors of performance on (morpho)syntactic production, treatment programmes should also include cognitive training targeting verbal WM.

2.2 Approaches, hypotheses and choice of method

The proposed project will build on Fyndanis et al. (in prep.) and test PWAA on verb-related morphosyntactic production within a cross-linguistic approach. The new data will feed into Fyndanis et al.'s combined dataset of 26 PWAA. Ideally, by the time the data collection and transcription will be completed, the expanded database will include the data of 146 PWAA (see Participants/Languages/Morphosyntactic categories subsection). This will enable us to carry out a more **ambitious study**, taking a **novel and promising methodological approach, i.e. a cross-linguistic machine learning approach** (see Data analysis subsection). For the first time, a **large number of factors** will be taken into account in a dataset that will consist of more than **27,000 data points**. **Six languages** (Norwegian, Greek, Italian, English, Russian, and German) and the data of **more than 140 PWAA** will be represented in this database. (Note that the vast majority of studies on agrammatic aphasia included small samples, i.e. groups of up to 10 PWAA). *Machine Learning Aphasia* will address a very important and "ambitious" question within **a methodological approach that will revolutionize cross-linguistic studies** by representing each morphosyntactic category/item as a **cluster of theoretically motivated features** and by analysing data on **multiple variables** employing **machine learning algorithms** (for more details, see Data analysis subsection). This approach, coupled with the fact that the datasets underlying the proposed project will consist of data from structurally and morphologically different languages (see Participants/Languages/Morphosyntactic categories subsection), will allow us to **abstract away from languages and morphosyntactic categories** and **focus on underlying factors** that are believed to be the **real sources of impairment in agrammatic morphosyntactic production**. **The proposed method, thus, will allow us to achieve a desirable level of abstraction and generalisation**. This kind of cross-linguistic approach to agrammatic aphasia has never been taken before. This approach, coupled with the powerful 'tool' of Machine Learning, constitutes a **significant advancement in methodology**. Given the importance of the research question that will be addressed, the proposed method and the scope of the study will also lead to **significant advances in scientific knowledge**. Based on Fyndanis et al.'s (in prep.) preliminary data, **we expect verbal WM and involvement of both integration processing and inflectional alternations to be among the best predictors** of level of performance (accuracy) on morphosyntactic production.

Participants/Languages/Morphosyntactic categories

In the existing database, three languages (Italian, Greek, German) and four verb-related (morpho)syntactic categories are represented: **Time Reference/Tense**, **Mood**, **Polarity**, and **subject-verb Agreement**. The proposed project will investigate the ability of PWAA to produce the above categories plus **Aspect**, and will focus on **five languages**: **Greek**, **Russian**, **Norwegian**, **Italian**, and **English**. We will test **20 Greek-**, **30 Russian-, 20 Norwegian-, 20 Italian-, and 30 English-speaking PWAA**, as well as groups of age- and education-matched healthy control participants (N=20-30 for each language) with constrained tasks tapping into verb-related morphosyntactic production (see Experiments subsection). Aphasia will be diagnosed on the basis of standardized batteries (where possible) such as the Western Aphasia Battery-Revised (Kertesz, 2006), the Boston Diagnostic Aphasia Examination-Short Form (Goodglass et al., 2001a; Messinis et al., 2013), and the Batteria per l'Analisi dei Deficit Afasici (Miceli et al., 2006). Following Goodglass et al. (2001b), diagnosis of agrammatic aphasia will be based on the analysis of samples of (semi)spontaneous speech. These samples will be elicited by means of picture description (Cookie Theft) and Stroke Story. The analysis of (semi)spontaneous speech will also provide indices of severity of agrammatism (e.g., Proportion of Grammatical Sentences and Mean Length of Utterance) that will be included as predictors in the analysis of the combined results.

The choice of languages this project will focus on is predominantly motivated by **structural/linguistic considerations**. For example, these languages differ in the **degree of verb-related morphological (inflectional) richness.** Russian, Greek, and Italian are morphologically rich, as all three languages overtly encode a wide array of verb-related (morpho)syntactic categories, including those the proposed study focuses on: Time Reference/Tense, Aspect, Mood, Polarity (i.e. affirmative vs. negative sentences), and subject-verb Agreement. In contrast, Norwegian and English verb-related inflectional morphology is relatively poor. In Norwegian, for example, the only (morpho)syntactic category that is overtly encoded in the verb is Time Reference/Tense, whereas in English there are only three verb-related suffixes: *–s*, *–ed*, and *–ing*; the former encodes 3rd person in singular number in present tense; the suffix *–ed* encodes Past Reference/Past Tense (e.g., walk*ed*) and passive voice in presence of the auxiliary verb "to be" (e.g., He was push*ed*); and the suffix *–ing* encodes progressive Aspect (e.g., He is runn*ing*). It has to be noted that Norwegian has a richer morphological system for Time Reference/Tense than English, because it has two classes of regular verbs (instead of one) and three different suffixes encoding past tense of regular verbs (i.e. *–te*: spis*te* 'ate'; *–et*: åpn*et* 'opened'; *–a*: kast*a* 'threw'). English only has one suffix: *–ed*. Moreover, the five languages under consideration structurally differ in the way they express sentential Negation. For example, sentential Negation is located high in the Greek, Italian, Russian and English syntactic hierarchy, but low in the Norwegian hierarchy (e.g., Philippaki-Warburton, 1998; Jensen, 2001; Ouhalla, 1990; Zanuttini, 1997). Moreover, the negative free-standing morphemes occupy the head position of Negation Phrase in the Greek, Italian and Russian syntactic trees, but the specifier position of Negation Phrase in the Norwegian and English syntactic trees (e.g., Jensen, 2001; Philippaki-Warburton, 1998; Rispens et al., 2001). In each language, as many of the aforementioned (morpho)syntactic categories will be tested as possible. Time Reference and Polarity will be tested in all five languages. Subject-verb Agreement, Aspect and Mood will be tested in all languages but Norwegian. (Norwegian does not overtly encode these morphosyntactic categories.)

<u>Experiments</u>
All morphosyntactic categories will be tested by means of constrained production tasks. Sentence completion tasks similar to those described in Fyndanis et al. (2018a; 2018b; 2018c) will be used to test subject-verb Agreement, Time Reference/Tense, Mood and Aspect. Anagram tasks similar to the production task described in Rispens et al. (2001) will be used to investigate participants' ability to construct negative and affirmative sentences (Polarity). All participants will also be administered cognitive tasks tapping verbal and nonverbal short-term and WM, processing speed, inhibition, and attention. The cognitive battery will consist of complex span tasks (e.g., digit forward span task, digit backward span task, digit ordering task), the verbal and nonverbal Stroop task, and the string of letters comparison task, among other tasks.

<u>Data analysis</u>
Machine learning algorithms will be used to analyse at least four different datasets: Dataset 1 will include cross-linguistic results on all five morphosyntactic categories under consideration (subject-verb Agreement, Time Reference/Tense, Mood, Polarity, Aspect). Dataset 2 will include cross-linguistic results on Time Reference. Dataset 3 will consist of cross-linguistic data on Time Reference/Tense and Aspect. Dataset 4 will contain cross-linguistic results on Polarity. Each dataset will include all relevant variables taken into account by Fyndanis et al. (in prep.) (see section 2.1) plus some additional variables (see below). These datasets will underlie different –but related–studies, as all of them will contribute to addressing the main questions of the proposed project. Although the study based on Dataset 1 appears to be the most relevant study for addressing our main questions, the studies based on Datasets 2-4 will offer additional insights into specific morphosyntactic phenomena, as they will take into account variables not included in Dataset 1, but are potentially relevant to these phenomena and their inclusion is theoretically motivated. For instance, in addition to the variables included in Dataset 1, Datasets 2-3 will also take into account material-specific variables such as lemma and lexeme frequency of occurrence, age of acquisition, length, phonological complexity and phonological neighbourhood density of the target verb form. The additional variable taken into account in Dataset 4 will be the language-dependent position of the negative marker in the Negative Phrase (i.e. specifier or head position) and the presence or absence of interference between this position and verb movement in each language (see Rispens et al., 2001; Bastiaanse et al., 2002). The reason these additional variables will not be included in Dataset 1 is that, in each dataset, all variables should be shared by all categories/items. Frequency and age of acquisition of the verb, for example, do not seem to be relevant to Polarity, or at least the inclusion of this variable in the items tapping Polarity would not be theoretically motivated. Dataset 2 and Dataset 3 will lead to studies addressing not only the main questions of the proposed project but also additional psycholinguistic questions, which are discussed in Fyndanis et al. (2018a) and Fyndanis and Themistocleous (under review).

Just like in the machine learning study described in Fyndanis et al. (in prep.), the items of each condition will be represented as clusters of potentially relevant features, such as ±*involvement of integration processes*, ±*involvement of inflectional alternations*, and *low/middle/high position in the syntactic hierarchy*. Russian, Norwegian, Greek, English and Italian present both commonalities and (morphological and structural) differences in way they encode the (morpho)syntactic phenomena under study. Given these cross-linguistic differences, the cluster of features associated with a given category may have different values depending on the language. As one may infer from Table 1, the value of the feature ±*involvement of integration processes* is language-independent, because some categories involve integration processes in all languages (e.g., Time

Table 1. Relevant properties of categories being tested (not exhaustive list)

Morphosyntactic category	Integration processes	Inflectional alternations	Position in the syntactic tree
Mood in Russian	+	–	high
Mood in Italian	+	+	middle
Mood in Greek	+	–	high
Polarity in Greek, Italian, Russian and English	+	–	high
Polarity in Norwegian	+	–	low
Time Reference in all five languages	+	–	middle
Subject-verb Agreement in Greek, Italian, Russian and English	–	+	middle

Relevant studies: Ouhalla, 1990; Philippaki-Warburton, 1998; Antonenko, 2008; Fyndanis et al., 2018c; Jensen, 2001; Zanuttini, 1997.

Reference/Tense, Polarity) and others do not involve integration processes in any language (e.g., Agreement). On the other hand, the values of the features ±*involvement of inflectional alternations* and *position in the syntactic hierarchy* are language-dependent, as they vary as a function of the structural and morphological properties of the language; for example, this is the case with Mood (see Fyndanis et al., 2018c). The advantages of the cross-linguistic machine learning approach outlined above are summarised in the Participants/Languages/Morphosyntactic categories subsection.

3 Project management and cooperation

The project will be hosted by the Center of Excellence *MultiLing – Center for MultiLingualism in Society across the Lifespan* in the Department of Linguistics and Scandinavian Studies, University of Oslo. It will be managed by **Valantis Fyndanis,** who will be fully committed to the project (100% effort). Evidence for the management skills of Valantis Fyndanis is provided by the fact that he was the Principle Investigator on the Marie Curie project *MemoGram* (2013-2015), for which he established an international network of collaborators in four countries (Greece, Italy, Germany, USA) and successfully coordinated the efforts of all of them towards the goals of the project. MemoGram involved testing of persons with aphasia in three countries and testing of persons with Alzheimer's disease in two countries. Three journal papers connected to MemoGram have already been published (Fyndanis et al., 2018a; 2018b; 2018c) and one is under review (Fyndanis & Themistocleous). Moreover, in COST Action IS1208, Fyndanis was the Deputy Lead of Working Group 2, member of the management and executive committees, and one of the two financial rapporteurs. He also organized a COST writing meeting in Athens (20-21 November 2016), which led to a journal publication (Fyndanis et al., 2017a).

Machine Learning Aphasia will also include a project team ("core group") consisting of **three senior researchers** who are **world experts in aphasia research** (Prof. David Caplan, Harvard Medical School/Massachusetts General Hospital, USA; Prof. Gabriele Miceli, University of Trento, Italy; Prof. Olga Dragoy, National Research University–Higher School of Economics, Russia) and **two junior promising researchers**, one of whom is also clinician (Dr. Monica Knoph, University of Oslo & Statped, Norway, and Dr. Charalambos Themistocleous, University of Gothenburgh, Sweden & Johns Hopkins University, USA). All the members of the core team have **impressive publication records** and are **experienced with (inter)national collaboration on projects and with supervision of younger researchers and students**. Additionally, the senior members are **very experienced with project management**.

The project, thus, **will utilise both national** (Fyndanis, Knoph) **and international** (Miceli, Caplan, Dragoy, Themistocleous) **expertise**. Since this project involves testing in five countries, it could not be implemented without **international cooperation**. Valantis Fyndanis has already collaborated successfully with some of the members of this network (e.g., Gabriele Miceli, David Caplan, Charalambos Themistocleous, Monica Knoph) on his Marie Curie project *MemoGram* and/or on his main project at MultiLing, and this collaboration resulted in high quality journal publications (e.g., Fyndanis et al., 2018a; 2018b; 2018c) and in several refereed conference presentations and papers. Moreover, the proposed project heavily draws on existing resources including tasks that have been already used successfully (see Experiments subsection), infrastructures (e.g., labs and hospitals/clinics – see details in WP3 description below), and expertise provided not only by the project core group but also by the host organization. For example, the project will draw on the expertise of respected scholars affiliated with MultiLing, such as Prof. Hanne Gram Simonsen and Prof. Mira Goral, and of MultiLing's Scientific Advisory Board, which includes internationally acclaimed researchers in the field of aphasiology such as Prof. Loraine Obler and Prof. Brendan Weekes.

The proposed project is divided into five Work Packages (WPs). WP1 is the development of experimental batteries in the five languages involved. WP2 involves applications for ethics approval. WP3 involves participant recruitment and data collection and transcription. WP4 involves data analysis and interpretation of results. WP5 contains dissemination activities and milestones. As can be seen below, some of the WPs will overlap in time, which is common practice in this kind of studies. For instance, WP2 will largely overlap in time with WP1. Furthermore, WP4 will largely overlap in time with WP5. More details about these WPs follow.

WP1: Development of Experimental Batteries (Month 1 – Month 8)

During the first eight months of the project Valantis Fyndanis will closely collaborate with Gabriele Miceli, Olga Dragoy, David Caplan and Monica Knoph on the development of the experimental batteries that will be administered to the participants of the five language communities involved in this project. These batteries will consist of tasks tapping morphosyntactic phenomena (i.e. subject-verb Agreement, Time Reference/Tense, Polarity, Mood, Aspect) and cognition (e.g., Working Memory, executive function, processing speed, etc.). To finalise the experimental batteries, their initial versions will first be administered to at least ten young healthy individuals per language. If problems arise for some trials of the language tasks, these will be corrected or replaced with new ones and the pilot administration of these tasks will be repeated. *Milestones/Deliverables*: Finalised batteries (deliverables in the form of a USB containing all the relevant documents).

WP2: Applications for Ethics Approval (Month 5 – Month 8)

WP2 involves all procedures needed to obtain Ethics Approval for the proposed project. Valantis Fyndanis will apply for Ethics Approval to REQ in Norway as well as to General University Hospital of Patras and to Evexia Rehabilitation Center in Thessaloniki, Greece. David Caplan will apply to Partners Human Research Committee/IRB in Boston, USA. Olga Dragoy will apply to the Committee on Interuniversity Surveys and Ethical Assess of Empirical Research of the National Research University Higher School of Economics in Moscow, Russia. Gabriele Miceli will apply to the University of Trento in Rovereto/Trento, Italy. (Most Italian-speaking participants will be tested at the Center for Neurocognitive Rehabilitation, which is affiliated with the University of Trento). *Deliverables*: Letters of approval from the relevant Ethics Committees.

WP3: Participant Recruitment, Data Collection, and Data Transcription (Month 8 – Month 36)

Since the proposed project constitutes a cross-linguistic study that involves testing native speakers of five different languages (Norwegian, Russian, Greek, Italian, Russian) living in their home countries, **each member of the project team will be in charge of recruiting and testing participants in one of the five countries involved**, except for Charalambos Themistocleous. **Valantis Fyndanis, Monica Knoph, Gabriele Miceli, Olga Dragoy, and David Caplan will be in charge of participant recruitment and data collection and transcription in Greece, Norway, Italy, Russia, and USA, respectively**. For participant recruitment, pools of PWAA connected to a number of hospitals and clinics will be used: e.g., *Sunnaas sykehus*, *Oslo university hospital* and *Oslo Voksenopplæring Nydalen* in Oslo, Norway; *Massachusetts General Hospital*, Boston, USA; *Center for Neurocognitive Rehabilitation*, Rovereto, Italy; *General University Hospital of Patras* and *Evexia Rehabilitation Center*, Thessaloniki, Greece; and *Center for Speech Pathology and Neurorehabilitation*, Moscow, Russia. Five research assistants will be employed, one in each country, to carry out participant recruitment and data collection and transcription under the supervision of Valantis Fyndanis and the project core member in charge. Participant recruitment, data collection and data transcription will take place simultaneously in the five countries involved. Each partner will store anonymized data in password-protected drivers/hard discs, and Valantis Fyndanis will be in charge of collecting copies of the datasets from each participating country and of merging the datasets into different unified datasets (see Data analysis subsection). The unified datasets will be stored in password-protected drivers of the University of Oslo. ***Deliverables***: Transcribed data.

WP4: Data Analysis and Interpretation of Results (Month 37 – Month 39)

Charalambos Themistocleous will be in charge of the **statistical analyses** of the data, including the use of **machine learning** algorithms/models. Themistocleous is an expert in statistics for behavioural sciences and in machine learning, and has recently published high quality machine learning studies (e.g., Grohmann et al., 2017; Themistocleous, 2016; 2017a; 2017b) as well as an introductory textbook in statistics (Themistocleous, 2015). He will closely collaborate with Valantis Fyndanis and the other members of the core group on the interpretation of the output of the analyses. *Milestones/Deliverables*: Word document including a summary of results and their interpretation.

<u>WP5: Dissemination Activities and Milestones (Month 37 – Month 48)</u>
WG5 contains dissemination activities and milestones. *Milestones/Deliverables*: at least **seven presentations at the most relevant international conferences**, at least **five articles published in or submitted to prestigious international refereed journals**, **one book, and two symposia** (one at MultiLing, University of Oslo, and one at Science of Aphasia). Outreach activities will also take place (see section 5).

Experience suggests that details of the work plan above may change slightly, but the general structure will be adhered to. Regular Skype meetings (once a month) will take place during which Valantis Fyndanis and all core members will discuss and address issues and unexpected problems. In addition to these regular meetings, Fyndanis will always be available and keen to discuss issues will all core members and research assistants. This will help avoid unnecessary delay in the implementation of the project. It has to be noted that, once the planned studies have been published, the anonymized database will be made available to the scientific community.

4 Key perspectives and compliance with strategic documents

4.1 Compliance with strategic documents
The proposed project is in compliance with the strategic priorities of the University of Oslo (UiO) for *Life Science*[1] (UiO2020[2]), and further anchored in UiO's strategic priorities as stated in *Quality and Relevance, Academic Priorities for Research and Education at the University of Oslo*: "Language and cultural studies will be further developed in line with increasing globalization and the growth of the multicultural society." Moreover, Clinical Linguistics is singled out as a promising field of cross-disciplinary research.[3]

4.2 Relevance and benefit to society
Our project will advance the frontier of research on aphasia, a neurological condition with devastating effects on the individual with aphasia and their caregivers/family, and on **society** at large. The "basic research knowledge" that will be generated during the implementation of *Machine Learning Aphasia* is expected to have **significant clinical implications** for PWAA, as the findings about the best predictors of morphosyntactic production in agrammatic aphasia will inform and improve treatment programmes. Improved treatment programmes will lead to improved quality of life of PWAA and their families, which of course constitutes "benefit to society". The proposed project will also be a **significant contribution to cognitive science** as it will advance our understanding of the complexities underlying morphosyntactic production. Therefore, the project has the **potential to impact on different academic disciplines** (e.g., speech language pathology, psycho-/neurolinguistics, theoretical linguistics, and cognitive neuropsychology) **as well as stakeholders** such as **PWAA, their families, caregivers** and **speech language pathologists**.

4.3 Environmental impact
There is no particular environmental impact involved in this project.

4.4 Ethical perspectives
The proposed study will adhere to the ethical standards of the Declaration of Helsinki for the protection of all research subjects. The study will obtain ethics approval in all countries involved (see section 3, WG3), and all participants will give informed consent before taking part.

4.5 Gender issues
Machine Learning Aphasia's core group consists of four men (Valantis Fyndanis, David Caplan, Gabriele Miceli, and Charalambos Themistocleous) and two women (Monica Knoph and Olga Dragoy). However, we will seriously address the issue of equal opportunity and the gender perspective, especially in the recruitment of the research assistants who will contribute to WPs 1-3. Thus, we will hire more female than male research assistants so that we can achieve an ideal gender balance within the extended project group. This is also in alignment with the strategies for gender balance at the *Center for Multilingualism in Society across the Lifespan* (*MultiLing*), as highlighted in the Center's annual report.[4] *Gender* will also be included as one of the subject-specific predictors/factors in the machine learning component of the proposed study.

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[1] http://www.uio.no/forskning/vi-forsker-pa/naturvitenskap-teknologi/lv-strategi.pdf
[2] https://www.uio.no/english/about/strategy/Strategy2020-English.pdf
[3] http://www.uio.no/forskning/tverrfak/Kvalitet-og-relevans-kortversjon.pdf
[4] www.hf.uio.no/multiling/english/about/strategy/

5 Dissemination and communication of results

The results of the proposed study will be presented at the most relevant and prestigious international conferences (e.g., *Academy of Aphasia Annual Meeting*, *Science of Aphasia conference*) and will be published as long scientific articles in high impact factor journals (e.g., *Cortex*, *Cognition*). The main deliverables will be at least **seven conference presentations,** at least **five published or submitted journal papers, one book** compiling all the results of the project (which will be published after the journal papers have been published), and **two symposia**: one will take place at MultiLing and one at Science of Aphasia. **Outreach activities** (i.e. dissemination initiatives directed to non-academic audiences) will also take place. These activities will include:

1) **Setting up a *Facebook* page** with a brief presentation of *Machine Learning Aphasia* and links to relevant websites (e.g., websites of the participating departments/universities, clinics and researchers). There will be regular updates on the progress of the work.
2) **Creation of a dedicated interactive webpage**, linked to MultiLing's website, with longer and more formal presentations of the project, including all the relevant links (see above). Work progress and problems will be illustrated in detail and regularly updated, focusing on scientific or technical issues.
3) **Production of video-clips and podcasts** presenting the project and its outcomes in a simple, comprehensible way. These video-clips and podcasts will be released on MultiLing's webpage, on the *Machine Learning Aphasia* webpage, on the Facebook page, and on YouTube.
4) **Organisation of Workshop Days for stakeholders in the participating countries.** In these events, the results and clinical implications of the project will be presented to stakeholders (i.e. individuals with aphasia, family members, clinicians, speech language therapists and researchers working on aphasia) in an accessible and engaging way. Fruitful discussions between Valantis Fyndanis or the core members of *Machine Learning Aphasia* and the stakeholders will follow.
5) **Articles or interviews** in (local and non-local) **newspapers and radios** in the countries involved.
6) A **Workshop Day for university students** will be organised by Valantis Fyndanis at the University of Oslo, Norway, in which *Machine Learning Aphasia* and its objectives will be presented in a simple and appealing way, in order to expose students and pupils to science, research and innovation, and to develop their motivation to embrace research careers.

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