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# The complex relationship between pre-stroke and post-stroke language abilities in multilingual individuals with aphasia

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**ABSTRACT**

**Background**: While many studies that focus on assessment or intervention in multilingual people with aphasia report both pre-stroke proficiencies and post-stroke language abilities, the relationship between them is not always clear.

**Aim**: We illustrate the relationship between pre-stroke language proficiencies and post-stroke language abilities by examining the factors that contribute to impairment patterns in multilingual people with aphasia.

**Main contribution**: We demonstrate that it is preferable to assess proficiency comprehensively by considering both absolute and relative pre-stroke proficiencies in addition to pre-stroke language use and exposure as well as absolute and relative post-stroke language abilities within the context of post-stroke language exposure and use. Moreover, we suggest referring to post-stroke *language abilities*, rather than *proficiency* to minimize the confusion of stroke-related effects and proficiency-related effects on performance.

**Conclusions**: Post-stroke language abilities are a complex consequence of a multitude of factors, including language background, pre-stroke proficiency, attrition of one or more languages, language of the environment (as it relates to exposure and use), and brain lesion. We aim to bring this issue to the forefront of research and clinical work, to better understand how to serve multilingual populations in the aphasia clinic.

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Multilingual; proficiency; attrition; language environment; brain lesion

## 1. Introduction

In this paper, we review the challenges related to classifying language impairment in multilingual people with stroke-induced aphasia. In addition to age of acquisition (AoA), a variable that has been much discussed in the literature, we consider the interaction between language exposure and use, as they relate to attrition and language environment both *pre-stroke* and *post-stroke*, and how each contributes to pre-stroke language proficiency and post-stroke language abilities. Furthermore, we discuss how establishing lesion site will contribute to the classification of language impairment in multilingual

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individuals, together with objective measures of post-stroke abilities. We then describe 13 case studies that illustrate the contribution of three factors: attrition, language of the environment, and brain-lesion site, and discuss for each case the relation between pre-stroke proficiency and post-stroke language abilities. We also identify the tools and resources that are currently available to assess pre-stroke proficiency, exposure and use, and post-stroke language abilities. We demonstrate that, by better understanding the factors involved in defining and assessing post-stroke language abilities and their relation to pre-stroke proficiency, exposure and use, we can improve our approach to language research in multilingual individuals with aphasia, as well as to language assessment and treatment in multilingual populations in the aphasia clinic.

### 1.1. Multilingualism

Multilingual people, a linguistically and communicatively heterogeneous group, are those who use more than one language in their everyday life (e.g., Butler, 2013; Grosjean, 2013). Many factors affect multilingual individuals' proficiency and use of any given language, including AoA, manner of acquisition, daily use of and exposure to each language (which are strongly influenced by the language of the environment), linguistic similarities and differences for each language pair, and accepted social norms of language mixing (e.g., Butler, 2013; Centeno, 2007; Grosjean, 2013; Muñoz, Marquardt, & Copeland, 1999). Different languages are often used in varying linguistic and/or communicative domains so assessing languages in multilingual populations will require testing different language modalities in a variety of contexts (e.g., Centeno, 2007; Grosjean, 2013).

### 1.2. The problem of determining language proficiency of multilingual individuals

Determining pre-stroke language abilities is not exclusive to multilingual individuals, but the range of abilities is greater among multilingual people than among monolingual people. Healthy monolingual speakers of any language evidence a range of skills for any given language domain when tested with standard language assessments (e.g., Bell & Perfetti, 1994; Pakulak & Neville, 2010; Weber-Fox, Davis, & Cuadrado, 2003), and their skills are closely connected with education level (e.g., Pakulak & Neville, 2010). Multilingual individuals show a wide range of proficiencies in a variety of language measures (morphosyntax, syntax, vocabulary, phonology, etc.) and language modalities (understanding, speaking, reading and writing), depending on their language history and degree of mastery.

Therefore, in monolingual individuals with aphasia, it is usually possible to obtain sufficiently reliable information about pre-stroke skills via questionnaires relating to each of the different language modalities (although few studies of monolingual speakers report such information), together with information about education level (which is virtually always reported). Information about post-stroke language abilities can be obtained via direct language testing; in many languages there are standardised language assessments for monolingual individuals with aphasia. It is then usually straightforward to identify the aspects of language affected by the stroke, using information from post-stroke language assessments together with the identification of the brain-lesion site. In multilingual individuals with aphasia, however, understanding how the stroke affects patients' languages is not so straightforward. Language abilities measured post-stroke will be affected not only by the stroke, due to lesions in the language network and/or language-control network (e.g., Abutalebi & Green, 2007; Catani & Bambini, 2014; Hickok & Poeppel, 2007; Hope et al., 2015), but also by pre- and post-stroke variation in language abilities and use (e.g., Centeno, Ghazi-Saidi, & Ansaldo, 2017; Roberts, 2008).

In multilingual populations with aphasia, pre-stroke proficiency has consistently been assumed to affect deficit and recovery patterns of language (e.g., Ansaldo & Saidi, 2014; Faroqi-Shah, Frymark, Mullen, & Wang, 2010; Goral, Rosas, Conner, Maul, & Obler, 2012; Lorenzen & Murray, 2008), but in many studies the term *proficiency* is poorly defined or partially determined (Barrett, 2018). Moreover, many researchers discuss both pre-stroke and post-stroke proficiency; we argue that this construct is confusing, because the term *post-stroke proficiency* does not indicate what part of the "proficiency" is stroke-related, and what part is related to pre-stroke language abilities.

### *1.3. The challenge of determining parallel vs. non-parallel language impairment*

In multilingual individuals with aphasia, language skills and language deficits are often identified as relative abilities. Patterns are called *parallel* or *non-parallel* and refer not to absolute language abilities (i.e., the specific skills and/or deficits in each language in each modality) but rather to the abilities in one language compared to the other (e.g., Paradis, 1977, 1998). However, not all researchers are specific as to what they mean by parallel language deficits; sometimes they appear to mean that both languages are similar in abilities and deficits post-stroke, regardless of pre-stroke language proficiency (e.g., Van der Linden et al., 2018), and, sometimes, parallel deficits mean that if pre-stroke language skills were not comparable, the same discrepancies remain post-stroke (e.g., Albert & Obler, 1978; Barrett, 2018; Paradis, 1993). It is therefore necessary to be specific regarding the skills of each language post-stroke relative to pre-stroke (e.g., Butler, 2013).

Of course, there is little opportunity to formally assess pre-stroke language proficiency in multilingual individuals with aphasia (as opposed to post-stroke language abilities); questionnaires or interviews may be administered but they are not always reliable for several reasons. First, many people with aphasia have difficulty rating their pre-stroke language skills (Kiran & Roberts, 2012), especially when the questionnaires are complex and require detailed information. Moreover, their family members and other caregivers often find estimating the patient's pre-stroke abilities in each of their languages challenging too. Second, self-rating, used in many questionnaires, has been shown to be poorly correlated with objective measures (e.g., Gollan, Weissberger, Runnqvist, Montoya, & Cera, 2012). Third, diverse questions and phrasing are used in different questionnaires, so it is difficult to compare across studies. Often researchers only identify self-reports of pre-stroke proficiencies, or state relative rather than absolute pre-stroke language skills (Barrett, 2018). Moreover, absolute pre-stroke proficiency for each language is difficult to determine, considering that proficiency is dynamic and fluctuates across the lifespan (e.g., De Bot, 2008; Grosjean, 2013).

### *1.4. The relationship between language proficiency and language use*

Language proficiency is closely related to AoA; it is often – albeit not always – the case that early acquisition is associated with higher proficiency than late acquisition.

Furthermore, manner of acquisition is also related to AoA, since languages that are acquired in early childhood are acquired implicitly through immersion; later-acquired languages may be learned through formal teaching, immersion or both (Paradis, 2004). Thus, manner of acquisition is also indirectly related to language proficiency. In their review of 130 cases reported in studies published between 2000–2018, Kuzmina, Goral, Norvik, and Weekes (2019) suggest that AoA is a strong predictor of post-stroke language abilities. This finding is consistent with the idea that in many cases, the first-acquired language, L1, is the most proficient language and remains so across the lifespan. However, language proficiency may change due to variations in language use and exposure over time (e.g., Centeno & Ansaldo, 2016). Therefore, in multilingual people for whom L1 becomes the less proficient language at some point, the question of deficit and recovery patterns after a stroke is further complicated. Such fluctuations characterise pre-stroke proficiency as well as post-stroke language abilities (e.g., Brozgold & Centeno, 2007).

Pre-stroke, changes in language use and exposure at any given period occur for many reasons such as those linked to migration, to changes in a work-setting where one language is used preferentially, to changes in personal relationships, and to changes in interests and hobbies that include learning and using certain languages. If a language falls out of use, or its use is reduced, attrition may occur (Keijzer & De Bot, 2019; Kohnert, 2013; Köpke, 2019; Obler, 1982; Schmid & Jarvis, 2014). For example, when one language becomes dominant in the environment of a multilingual individual, the other languages may be harder to access, even if all languages are used regularly (Linck, Kroll, & Sunderman, 2009), resulting in attrition. Additionally, aging effects on language may also contribute to changes in perceived proficiencies of both monolingual and multilingual individuals (Au et al., 1995; Goral, 2019; Lerman & Obler, 2017).

The phenomenon of attrition in neurologically healthy individuals is most well-documented following immigration to a country where a new language is spoken, although other changes in the language environment, as noted above, may also result in attrition (Higby, Lerman, Korytkowska, Malcolm, & Obler, 2019). Different aspects of language attrite at different rates, and the process of decline is subtle. Mapping the rate of attrition is complex and is based on factors such as amount of contact with the attriting language, the amount of overlap between the language(s) still being used and the language which is attriting, and possibly length of residence (but not as a linear relationship) (Goral, Libben, Obler, Jarema, & Ohayon, 2008; Higby et al., 2019; Schmid, 2011).

Word-retrieval difficulties are a particularly salient phenomenon in attrition, resulting in slow and laborious retrieval, often incorrect, with an increase of dysfluency markers (Schmid & Fägersten, 2010; Schmid & Köpke, 2009). Additionally, lexical diversity is reduced, and the richness of the language may decrease (Higby et al., 2019). However, attrition appears to result in a loss of access, rather than an absolute loss of language; often attritors are unable to produce words but can easily identify them out of a number of choices (Ammerlaan, 1996). Thus, attrition may lead to language characteristics that are consistent with those observed in individuals with expressive or non-fluent aphasia, such as word retrieval difficulties, increased dysfluency markers, and better language comprehension than production.

In multilingual people with aphasia, attrition may have begun before the stroke, or can begin following the stroke (due to a change in post-stroke language environment, or due to non-parallel language impairment resulting in an imbalance of language use with the less-used language eventually attriting). A language that was highly proficient but has attrited has the potential to be rehabilitated, as opposed to a language that was never fully proficient which can presumably only be rehabilitated relative to pre-stroke proficiency in each language modality. Therefore, understanding whether attrition occurred pre-stroke is crucial to interpreting the results of post-stroke language assessment, and, together with determining *peak proficiency*, to understanding the potential for language rehabilitation.

Every multilingual individual has a *peak proficiency* for each language, which is the point in their lifespan where proficiency in different modalities in any given language is at its highest. This may be a narrow time interval, just before an acquired language is no longer maintained, or it may be that the peak proficiency of a language is upheld over most, or all, of the lifespan. By contrast, overall proficiency is a coarse measure of how proficient someone is in any given language across the lifespan. When assessing pre-stroke proficiency, it is therefore necessary to ascertain not only the peak proficiency of any given language, but also when it occurred (e.g., immediately before the stroke, many years before the stroke, etc.). This information could be obtained by directly asking people with aphasia and their family members about proficiency, use and exposure at different age-periods, for different language modalities, but few existing questionnaires attempt to elicit this information (e.g., Montrul, 2012).

Post-stroke, language use and exposure will be directly affected by the language environment, which may change after a stroke. Contact with each language in the environment may not be equal post-stroke to the individual's pre-stroke language contact. For example, if a multilingual individual with aphasia used language X at work but quits work after the stroke, or if only language Y is used within a hospital setting (e.g., as the language in the environment or the language targeted in treatment), attrition is likely to occur over time in the less-used and/or less-treated language.

### 1.5. Brain lesions in multilingual individuals with aphasia: impairment of language or of control

Changes in language abilities pre- to post-stroke have long been accepted to result from damage to the language network, which includes both cortical and subcortical structures (e.g., Hallowell, 2017; Hickok & Poeppel, 2007; Hoffmann & Chen, 2013; cf. Fedorenko & Thompson-Schill, 2014). While there is no one-to-one relationship between site and size of lesion and aphasia type and severity, more specific predictions about aphasia are becoming possible with the advancement of neuroimaging techniques that take into account both grey and white matter (e.g., Yourganov, Smith, Fridriksson, & Rorden, 2015; Zavanone et al., 2018). However, lesion site (and size) alone is still not considered to be a good predictor of language recovery for people with aphasia (e.g., Plowman, Hentz, & Ellis, 2012).

In multilingual individuals, damage to the language network is hypothesised to bring about similar impairment in both languages, relative to pre-stroke language proficiency, because the different languages of multilingual people are hypothesised to be subserved by predominantly overlapping brain regions (e.g., Abutalebi, Cappa, & Perani, 2001; Higby, Kim, & Obler, 2013; Perani et al., 1998). However, some researchers have suggested that different languages may be associated with differential brain activation (e.g., Giussani, Roux, Lubrano, Gaini, & Bello, 2007), possibly related to proficiency levels (e.g., Sebastian, Laird, & Kiran, 2011).

Damage to the language-control network may occur in addition to or instead of damage to the language network. The language control network is responsible for selection, inhibition, planning, switching and maintaining any given language at a given time (Abutalebi & Green, 2007). Damage to the control network has been hypothesised to result in differences in impairment across languages of multilingual individuals because problems in the control network render one language more accessible than another (e.g., Green & Abutalebi, 2008; Paradis, 1998). Therefore, brain-lesion site will contribute to whether post-stroke language impairment appears parallel or non-parallel compared to pre-stroke language proficiency (e.g., Obler & Mahecha, 1991).

## 2 An illustration: selected case studies

Whereas many studies of multilingual individuals with aphasia address some of the above-mentioned variables, few consider the interaction among them. We therefore consider next the relationship between pre-stroke proficiency and post-stroke language abilities and how they are affected by pre- and post-stroke language use and exposure. These relationships, in conjunction with the specific brain lesion, should help us identify the influences on post-stroke language abilities. To this end, we present and discuss 13 case studies from published literature and from our own clinical research that do not follow the patterns of relative pre- and post-stroke language abilities expected from the results in Kuzmina et al. (2019) and/or that exemplify the interaction among the factors reviewed above. Of these, we focus on three main factors that likely interact to contribute to the relationship between pre- and post-stroke language patterns other than AoA: (1) pre- and post-stroke attrition, (2) language of the environment, and (3) brain-lesion site. These factors are concrete and assessable, but, of course, factors 1 and 2 are highly interrelated; they influence and are influenced by language use and exposure, and, consequently, by pre-stroke proficiency and post-stroke language abilities. See Table 1 for an overview of factors affecting post-stroke language abilities for the 13 case studies discussed.

### *2.1 Selected case studies: pre- and post-stroke attrition*

Filiputti, Tavano, Vorano, De Luca, and Fabbro (2002) discussed a case involving pre-stroke attrition in a participant who had not used his L1 for many years before he had a stroke at age 55, while he used L2, L3 and L4 continuously up until the stroke. In this study, L1 was Slovenian, Italian (L2) was acquired from age 6, and from age 11 Friulian was added (L3). The participant acquired his L4 – English – at age 21 when he immigrated to Canada. Fifteen years later he returned to Italy, where he used Italian, Friulian and English frequently. He rated his overall pre-stroke proficiency in Italian and English as high and in Friulian as moderate; he did not use Slovenian again after returning to Italy. Based on AoA only, we would expect Slovenian to be the language best spared post-stroke but his post-stroke Slovenian was assessed as being of low proficiency, highly likely due to pre-stroke attrition, together with any effects of language impairment from the brain lesion (Filiputti et al., 2002).

**Table 1.** An overview of factors that may affect post-stroke language abilities for each of the 13 case studies that are discussed.

| | Source | Languages | Age at stroke (yrs) | Brain lesion | AOA of non-L1 | Pre-stroke proficiency | LOE (society) post-stroke | LOE (home) post-stroke | Language recovery patterns | Attrition[a] |
|---|---|---|---|---|---|---|---|---|---|---|
| Case 1 | Filiputti et al. (2002) | L1 – Slovenian<br>L2 – Italian<br>L3 – Friulian<br>L4 – English | 55 | Left middle cerebral artery region; alteration in the left temporo-parietal lobe, including the insula and the gyrus supramarginalis | L2 – 6 yrs<br>L3 – 11 yrs<br>L4 – 21 yrs | L2 = high<br>L4 = high<br>L3 = moderate<br>L1 = low | L2 and L3 | L2 and L4 | Similar abilities for L2 and L4. Better abilities in L2 and L4 than in L3. Better abilities in L3 than in L1 | Pre-stroke attrition of L1 |
| Case 2 | Knoph et al. (2015) | L1 – Japanese<br>L2 – English<br>L3 – German<br>L4 – Norwegian | 59 | Left hemisphere stroke | L2 – school-age<br>L3 – school-age<br>L4 – as an adult | L1 = high<br>L2 = high<br>L4 = high<br>L3 = moderate | L4 | L4 | Better abilities in L1 than in L4. Better abilities in L4 than in L2. Better abilities in L2 than in L3 | Pre-stroke attrition of L3 |
| Case 3 (EH02) | From our multilingual aphasia clinical research studies | L1 – English<br>L2 – Hebrew | 51 | Left thalamic haemorrhage | L2 – 6 yrs | L1 more proficient than L2 | L1 | L1 | Better abilities in L1 than in L2 | Post-stroke attrition of L2 |
| Case 4 | Meinzer et al. (2007) | L1 – French<br>L2 – German | 32 | Left middle cerebral artery region; anterior middle and superior temporal lobe, inferior frontal gyrus and Rolandic operculum, pre- and postcentral regions, posterior insula and putamen, superior and inferior parietal lobe | L2 – 3 yrs | L1 = high<br>L2 = high | L2 | L2 (strongly recommended by SLT) | Better abilities in L2 than in L1 | Post-stroke attrition of L1 |

(*Continued*)

**Table 1.** (Continued).

| | Source | Languages | Age at stroke (yrs) | Brain lesion | AOA of non-L1 | Pre-stroke proficiency | LOE (society) post-stroke | LOE (home) post-stroke | Language recovery patterns | Attrition[a] |
|---|---|---|---|---|---|---|---|---|---|---|
| Case 5 | Goral (2012) and Goral et al. (2013) | L1 – Persian<br>L2 – German<br>L3 – English | 28 | Large left CVA, including damage to frontal regions | L2 – 6 yrs<br>L3 – late childhood | L1 = high<br>L2 = high<br>L3 = high | L3 | L1 and L3 | Better abilities in L3 than in L1 and L2. Similar abilities for L1 and L2 | Post-stroke attrition of L1 and L2 |
| Case 6 | Kiran and Roberts (2010) – case 2 | L1 – Spanish<br>L2 – English | 87 | Left middle cerebral artery region | n/a | L1 high<br>L2 = high | L2 | L1 and L2 | Better abilities in L2 than in L1 | |
| Case 7 | Kiran et al. (2013) – case UT17 | L1 – Spanish<br>L2 – English | 52 | Left perisylvian area CVA | L2 – 6 yrs, in school in the U.S. | L1 = high<br>L2 = high | L2 | L1 and L2 (inferred) | Better abilities in L2 than in L1 | |
| Case 8 | Kiran and Roberts (2010) – case 1 | L1 – Spanish<br>L2 – English | 54 | Left middle cerebral artery region | L2 – 5 yrs, in school in the U.S. | L2 more proficient than L1, both high proficiency | L2 | L1 and L2 | Better abilities in L2 than L1 (more impairment to L1 than L2 post-stroke relative to pre-stroke proficiencies) | |
| Case 9 (EH03) | From our multilingual aphasia clinical research studies | L1 – English<br>L2 – Hebrew | 62 | Large left hemisphere stroke | L2 – 6 yrs | L1 more proficient than L2, both high proficiency | L2 | L1 | Better abilities in L1 than in L2 | Post-stroke attrition of L2? |
| Case 10 | Radman et al. (2016) – subject 3 | L1 – Italian<br>L2 – French | 63 | Damage to language control network only; left basal ganglia haemorrhage | L2 – 10 yrs | L1 = high<br>L2 = high | L2 | L2 | Better abilities in L2 than in L1 | |

(*Continued*)

**Table 1.** (Continued).

| | Source | Languages | Age at stroke (yrs) | Brain lesion | AOA of non-L1 | Pre-stroke proficiency | LOE (society) post-stroke | LOE (home) post-stroke | Language recovery patterns | Attrition[a] |
|---|---|---|---|---|---|---|---|---|---|---|
| Case 11 | Radman et al. (2016) – subject 4 | L1 – French<br>L2 – English | 49 | Damage to perisylvian regions only; left Sylvian ischemic stroke | L2 – 14 yrs | L1 more proficient than L2 | L1 | L1 | Better abilities in L1 than in L2 (parallel to pre-stroke abilities) | |
| Case 12 | Radman et al. (2016) – subject 5 | L1 – French<br>L2 – English | 79 | Damage to perisylvian regions only; left frontal, insular and Sylvian areas | L2 – 18 yrs | L1 more proficient than L2 | L1 | L1 | Better abilities in L1 than in L2 (parallel to pre-stroke abilities) | |
| Case 13 | Radman et al. (2016) – subject 2 | L1 – Italian<br>L2 – French | 65 | Damage to both language control network and perisylvian regions; left frontobasal areas | L2 – 24 yrs | L1 more proficient than L2 | L2 | L1 and L2 | Better abilities in L1 than in L2 (more impairment to L2 than L1 post stroke relative to pre-stroke proficiencies) | |

Note: AoA = Age of acquisition; LOE = language of the environment; L1 = first acquired language; L2 = second acquired language, etc.; SLT = Speech-language therapist; CVA = cerebrovascular accident.

[a]Attrition was not objectively measured in each case study, rather it was inferred by the authors based on the available information.

Another example of pre-stroke attrition affecting post-stroke language abilities is a case discussed by Knoph, Lind, and Simonsen (2015) who describe a quadrilingual participant with aphasia whose L1 (Japanese), L2 (English – acquired in school and through immersion when living in the UK as an adult, for several years) and L4 (Norwegian – acquired as an adult formally and through immersion when living in Norway) were all highly proficient and used daily at the time of the stroke at age 59, while living in Norway. Her L3 (German – acquired in school), although once highly proficient (she interpreted professionally between German and Japanese), was only of moderate proficiency at the time of the stroke, due to infrequent use in the years leading up to the stroke. After a left hemisphere stroke, her language abilities were low in German (L3), but remained high in Japanese (L1), moderate-high in Norwegian (L4), and moderate in English (L2). Based on AoA only, we would have expected English and German to be better spared post-stroke than Norwegian, that is, the one language the participant acquired during adulthood. However, her low post-stroke language abilities in German were likely due to pre-stroke attrition.

As discussed above, attrition can also occur post-stroke, and this was observed in a participant who took part in one of our clinical multilingual aphasia studies: EH02. EH02 is a 65-year-old English-Hebrew bilingual individual who lived in the US all his life. His native language was English (L1), and this remained his most proficient language across the lifespan. He acquired Modern Hebrew (L2) at school to a moderate proficiency[1], including literacy, and continued to use his Hebrew mostly through reading and later also through auditory comprehension and minimal production with his wife (a native Hebrew speaker) and her children from his early 40s into his 50s. The participant had a left thalamic haemorrhage at age 51, 14 years before he joined our study. After the stroke, he communicated almost exclusively in English (he had divorced his wife around the time of the stroke), with minimal receptive Hebrew activities through reading only.

EH02 reported pre-stroke language skills as highly proficient in English, with moderate peak proficiency in Hebrew, during the 10 years preceding the stroke. Post-stroke, he had mild anomia in English and moderate-severe expressive aphasia in Hebrew (based on the Western Aphasia Battery, Revised [WAB-R], Kertesz, 2006). While post-stroke language abilities here support the findings of Kuzmina et al. (2019) regarding AoA, the differences between the two languages are extreme, suggesting that other factors are also involved.

One factor would be the lesion site. A haemorrhage in the left thalamus may differentially affect the languages of a multilingual individual, due to cortical connections with the basal ganglia and frontal lobe, resulting in disruption to the language control network (e.g., Abutalebi & Green, 2007; Nadeau & Crosson, 1997; Verreyt, De Letter, Hemelsoet, Santens, & Duyck, 2013). However, in the case of EH02, we need to consider pre-stroke peak proficiency and post-stroke attrition, which likely contributed to the extreme differential impairment. If we assume that his language deficits in Hebrew are only due to his brain lesion, we could be distorting the expected potential treatment gains, resulting in erroneous treatment planning.

Indeed, an error analysis of responses in Hebrew (L2) from a comprehensive language assessment indicates additional possible sources of language difficulty, other than the stroke, and in keeping with EH02's report of rarely using Hebrew in the last 14 years. For example, he sometimes indicated that he did not know less frequent words: "I don't know how to say that in Hebrew", suggesting that they were never part of his lexicon.

Furthermore, the difference between post-stroke comprehension and production skills were greater in Hebrew than in English, with better comprehension than production in Hebrew, and more similar comprehension and production abilities in English. This may reflect his pre-stroke overall high proficiency in English and moderate peak proficiency in Hebrew, but it could also reflect attrition in Hebrew, because in attrition difficulties are more salient in production than comprehension. Other indications of attrition included the production in Hebrew of words with phonological errors, indicating that he vaguely remembered the words but could not fully retrieve them – a common phenomenon in a language that is attriting. In contrast, no phonological errors occurred in English. We conclude that in the case of EH02, his post-stroke language skills were likely a combination of his pre-stroke L1 and L2 proficiency, post-stroke attrition of L2, and the brain lesion.

An interesting case of actively encouraging a monolingual language environment post-stroke was described by Meinzer, Obleser, Flaisch, Eulitz, and Rockstroh (2007). They discussed a multilingual participant with aphasia whose L1 (French), together with L2 (German) that was acquired from age 3, were both highly proficient pre-stroke and used daily in Germany throughout childhood and adulthood. After a stroke at age 32, German was the language of the environment and the patient and his interlocutors used it almost exclusively, at the recommendation of the hospital's speech-language therapist (SLT). When the researchers assessed both languages 32 months post-stroke, German was less impaired than French, contrary to expectations based on AoA alone. It is likely that his poor French performance reflected attrition due to disuse post-stroke, rather than due exclusively to the large left perisylvian lesion, which might be expected to affect German and French in a parallel manner.

Another case involving post-stroke attrition is that of a Persian-German-English trilingual participant who acquired German (L2) formally and through immersion after moving to Germany from Iran at age 6, and English (L3) from late childhood, formally in school in Germany (Goral, 2012; Goral, Naghibolhosseini, & Conner, 2013). She later moved to the US at age 27; her German and English were both highly proficient in all modalities, and her spoken Persian (L1) was also highly proficient, but she had limited literacy in Persian. At age 28, while living in the US, she suffered a large left-hemisphere stroke that included frontal regions and received language treatment in English only in the ensuing years. Thirteen years post-stroke, the participant showed relatively high language abilities in English, and more prominent difficulties in German and Persian. Remarkably, English was the better spared language even though she frequently used all three languages to a high proficiency at the time of the stroke, and English was the language she learned latest of the three. Over time post-stroke, with English being used frequently (for both speaking and understanding), and Persian and German used receptively (but rarely spoken), English remained her most proficient language (Goral et al., 2013). We suggest that the language of the environment – English – was more activated and, therefore, better preserved than her other languages. This likely led to English being more easily accessed, resulting in post-stroke attrition of Persian and German during the post-stroke years.

### 2.2 Selected case studies: language of the environment

Recall the Knoph et al. (2015) case of a Japanese-English-German-Norwegian quadrilingual individual with aphasia: In addition to attrition in German (L3) we can also identify the effects of language environment on the participant's other languages. After a left hemisphere stroke, her language abilities remained high in Japanese (L1), moderate-high in Norwegian (L4), and moderate in English (L2). Since Norwegian (L4) was the only language learned as an adult, and L1, L2 and L4 were all highly proficient and used daily pre-stroke, it is unexpected that Norwegian (L4) was better spared than English (L2) post-stroke. However, recall that L4 was the language of the environment, so it was presumably more activated and thus more accessible than the other languages both pre and post-stroke.

Similarly, consider the Filiputti et al. (2002) case described above of a Slovenian-Italian-Friulian-English quadrilingual individual with aphasia. In addition to attrition of Slovenian (L1), we can also identify that the languages of the environment were better spared than the other languages. Post-stroke, the participant's Italian (L2) demonstrated the highest language abilities, arguably as the main language of both the home and the societal environments. Friulian (L3), the other language of the environment, demonstrated moderate post-stroke language abilities, in parallel with moderate pre-stroke language proficiency. However, post-stroke English (L4) was impaired more than Italian, even though they had both been of high proficiency pre-stroke, likely due to English being partially used in his home environment only.

Three cases described by Kiran and colleagues further support the hypothesis that language of the environment contributes to expected patterns of language impairment more than we might expect based only on pre-stroke proficiency levels (Kiran & Roberts, 2010; Kiran, Sandberg, Gray, Ascenso, & Kester, 2013). In each of their cases, Spanish was the L1 and English both the L2 and the main language of the environment. In two cases, Spanish and English are self-reported as equally and highly proficient pre-stroke, yet post-stroke Spanish is impaired more than English (Kiran & Roberts, 2010, case 2; Kiran et al., 2013, UT17). The third example involves a participant whose English was more proficient than Spanish pre-stroke, although both were considered highly proficient. Relative to pre-stroke abilities across languages, post-stroke Spanish was more impaired than English (Kiran & Roberts, 2010, case 1). These case studies all contradict the AoA findings of Kuzmina et al. (2019), supporting the hypothesis that the language environment in the years immediately before the stroke may help to preserve that language post-stroke, as argued by Pitres (1895) and Obler and Albert (1977), resulting in easier access and, therefore, better spared language abilities.

Clearly, there is a relationship between language attrition and the language of the environment, especially when the attriting language is not used in the environment. Of course, a language can undergo attrition even if it is the language of the environment but one that is not often used by the individual with aphasia. This is illustrated in the following case. EH03, who joined one of our clinical multilingual aphasia studies, acquired English from birth (L1) while living in the US and acquired Modern Hebrew in school from age 6 (L2)[1]. As a young adult, EH03 moved to Israel where he used both English and Hebrew daily to an overall high and literate pre-stroke proficiency. His main language at home was English, and at work was Hebrew. Following a large left hemisphere stroke at age 62, EH03 gave up work. Post-stroke, his main language was English at home and for his rehabilitation. He was exposed to Hebrew daily in the hospital on the rehabilitation ward; later on, he was exposed to Hebrew in the community, on television and during interactions with a few specific family members.

Medical reports observed that immediately post-stroke, EH03 had severe aphasia in both languages, with Hebrew worse than English. This relative (but not absolute) pattern remained six years later: assessed via the WAB-R (Kertesz, 2006), EH03 had severe aphasia in Hebrew, and moderate aphasia in English. Based on Kuzmina et al. (2019), we might expect this early highly proficient bilingual individual to have parallel impairment, but his language abilities were impaired in a non-parallel manner. It may be that the language of his post-stroke home environment – English – contributed to his improvement in English due to English being more active and thus more easily accessed than Hebrew. Of course, it could also be that the treatment provided in English added to the better post-stroke language abilities in English and that by not using Hebrew as much as English post-stroke, attrition occurred in Hebrew.

### 2.3 Selected case studies: brain lesions and language impairment in multilingual people

Relatively few published studies on multilingual people with aphasia provide sufficiently detailed information about brain lesions together with detailed information about pre- and post-stroke language abilities. Furthermore, it is often the case that the lesion affects both the language network and the control network, making it difficult to identify the effects of each on the behavioural data. One notable exception is a multiple case-study by Radman et al. (2016) that provides partial support for parallel vs. non-parallel impairment relative to lesions in the language network vs. the control network, respectively.

Radman et al. (2016) assessed five late-bilingual individuals (AoA >10 years) with aphasia during the sub-acute phase of their recovery and found that one of their participants (Subject 3) showed damage to the language control network only, two participants (Subjects 4 and 5) damage to the left perisylvian regions only (i.e., part of the language network), and one participant (Subject 2) damage to both networks[2]. Subjects 4 and 5 (language network damage) showed parallel language impairment, with L1 language abilities better than L2 both pre and post-stroke. Compare this pattern to Subject 3 (control network damage) who showed non-parallel language impairment, with parallel, high language proficiency pre-stroke and better production abilities in L2 than in L1 after the stroke. Furthermore, when damage occurred to both networks in Subject 2, a non-parallel language impairment was observed, with relatively more impairment to L2 than to L1 post-stroke compared to pre-stroke abilities, suggesting that L1 was relatively more accessible than L2 after the stroke. We therefore suggest that brain-lesion data are necessary to guide assessment of multilingual people with aphasia but cannot be used on their own to predict language patterns after a stroke. Other factors must be considered, such as language environment and attrition, and their effects on language abilities.

## 3 Discussion

It is clear from the case studies presented here that no single factor can predict post-stroke language abilities. Key to our ability to consider the interaction among these factors are our methods of collecting the relevant information. We turn next to a discussion about the measuring of language proficiency.

### *3.1 The construct "Language proficiency" in multilingual individuals with aphasia*

Based on the case studies described above, we reject the terminology *post-stroke proficiency* as misleading and unclear. Instead, we advocate for the term *post-stroke language abilities* to recognise both relative and absolute language abilities, which are influenced by lesion site, pre-stroke proficiency, and post-stroke language use. By appropriately collecting detailed information about pre-stroke language background and use, as well as a detailed account of the brain lesion, together with conducting thorough post-stroke language assessments, we can usually be confident about how much of any language impairment is a direct result of the stroke, and plan treatment accordingly. However, these data are often difficult to obtain; we next discuss some of the challenges and possible solutions to this problem.

### *3.2 Assessment of languages*

The necessity to fully assess pre- and post-stroke language abilities is undisputed in the field, however, the availability of resources to do this is limited. For monolingual people, pre-stroke language skills are usually estimated by asking questions about education level and literacy achievements. Post-stroke, there are standardised assessments to use in a number of languages, and any language impairment is assumed to be a direct result of the brain lesion alone. For multilingual people, this is obviously a more challenging undertaking. We need to assess post-stroke language impairment while considering that different levels of language abilities may have existed before the stroke or may have been exaggerated due to an imbalance in language use post-stroke (Kiran & Roberts, 2012). Even when a multilingual individual has high and parallel pre-stroke proficiency, we cannot be sure that any language difficulty is a direct result of the brain lesion. Furthermore, standardised assessments are rarely standardised on multilingual populations with an identical language background and culture of the multilingual individual who is being assessed in the clinic.

Therefore, collecting information about pre-stroke language proficiency, exposure and use is vital, and this information is usually obtained via comprehensive questionnaires (e.g., Kiran & Roberts, 2012). To begin with, it is necessary to identify the languages used pre-stroke by a multilingual individual with aphasia and the age and manner that each language was initially acquired. This is a relatively simple step in the assessment of this population; the information obtained is usually accurate, especially when corroborated by a family member. Knowing the AoA of each language can already provide some information about expected patterns of relative impairment (Kuzmina et al., 2019). However, additional information must be obtained in conjunction with AoA – AoA of L2 is not a good predictor of relative and absolute post-stroke language abilities if proficiency of L1 and L2 is not taken into account (e.g., Barrett, 2018; Kambanaros & Vansteenbrugge, 2006). Barrett found that in order to get a valid, comprehensive picture of pre-stroke proficiency, a number of variables need to be assessed: for L1, pre-stroke proficiency can be measured accurately by identifying the percentage of daily use, whether L1 was the language of education, the amount of exposure to L1, and a self-rating of language abilities; for L2, all of these factors should be used, together with AoA, family proficiency levels, and a self-rating for the amount of confidence in using the L2 (Barrett, 2018). When proficiency is measured in this way, information is collected regarding both absolute and relative proficiencies. This contrasts with studies where only relative proficiencies are provided, often just from asking the multilingual individual to give a self-rating (e.g., Mariën et al., 2017; Roberts & Deslauriers, 1999; Verreyt et al., 2013).

In addition, we need to consider factors such as peak language proficiency and attrition. Another important aspect of language use that is often overlooked is whether the multilingual individuals mixed their languages before the stroke, or whether they typically used one language at a time, depending on their interlocutors. This would be relevant to understanding any post-stroke language mixing behaviours (e.g., Goral, Norvik, & Jensen, in press).

Questionnaires such as the Bilingual Aphasia Test (BAT) History of Bilingualism questionnaire (Paradis, 2011), the Bilingual Aphasia Summary form (Kohnert, 2013), the Language Use Questionnaire (LUQ) (Kastenbaum et al., 2019) and a language use and language history questionnaire published by Muñoz et al. (1999) are available for use in our field, although some are more up-to-date and comprehensive than others. Also, other questionnaires for multilingual people can be adapted to be used for people with aphasia, such as the Language Experience and Proficiency Questionnaire (LEAP-Q) (Marian, Blumenfeld, & Kaushanskaya, 2007) and the Language History Questionnaire (LHQ) (Li, Zhang, Tsai, & Puls, 2014). However, for any questionnaire, an internal problem remains: how reliable are self-reports and self-ratings of a person after a brain lesion about their abilities from before the lesion? If we involve another person, such as a spouse or a child, they often can only comment on one language – the language they communicate in with that person. This is a conundrum that has yet to be solved adequately in our field.

The first step will be to find the balance between an excessive number of intricate questions in order to obtain all possible information, and fewer questions providing less specific information but more reliably collected. Barrett's (2018) study is an important step towards understanding what information is necessary to collect; the next step will be to collaborate within the field to reach as many multilingual people with aphasia as possible and test the soundness and dependability of available questionnaires. It is up to each clinician and/or researcher to build a picture of language history, background, exposure and use, and the likelihood of pre-stroke attrition for any given language, as well as to obtain detailed information about the regions and tracts involved in the brain lesion.

The availability of information regarding brain-lesion data, obtained either directly from the participant or from medical professionals, will depend on whether the speech-language therapy clinic is hospital-based or not and also on local laws concerning patient privacy. Often, SLTs receive general information regarding the stroke, such as "left hemisphere CVA" or "anterior infarct". However, if detailed brain-imaging data can be made available, SLTs can more effectively plan treatment by deciding how to separate (or not) the two languages during treatment, based on the involvement of impairment to the language control network. For example, if language mixing occurs, but no impairment to the language control network is observed, it may be that the language mixing is an attempt to bypass lexical retrieval difficulty, and, therefore, could be encouraged during treatment (e.g., Goral et al., in press; Lerman, Pazuelo, Kizner, Borodkin, & Goral, 2018).

In the context of pre-stroke language data and brain-lesion data, post-stroke language assessments can be better interpreted. To the extent possible, assessment should be completed in all languages of a multilingual individual with aphasia. If we use two standardised assessments, one for each language, we will get some information, but the norms provided will only be partially relevant. Of course, not every language has a standardised assessment, in which case we must skillfully use the best available assessment in that language. The BAT (Paradis, 2011) is a good resource, but mostly for moderate aphasia – for mild and severe aphasia many of the sub-tests will show ceiling or floor effects, respectively. The results of an assessment are best analysed quantitatively when possible, as well as qualitatively. Importantly, any diagnosis should be presented carefully; for example, using terminology such as "moderate-severe aphasia" in a language that was only moderately proficient pre-stroke, or had already undergone substantial attrition, without considering pre-stroke proficiency, is misleading and warps our understanding of aphasia as a language impairment due to a brain lesion. We advocate for consistently presenting post-stroke language abilities juxtaposed with pre-stroke language proficiency.

We know that the amount of time post-stroke that the assessment takes place will affect the stability of any results obtained. In the weeks immediately after a stroke, spontaneous improvement of the language impairment is common and, therefore, language abilities are not stable (e.g., Pedersen, Vinter, & Olsen, 2004; Pederson, Stig Jørgensen, Nakayama, Raaschou, & Olsen, 1995). While many researchers recruit participants during the chronic stage of aphasia, potentially to try to reduce the influence of spontaneous recovery (but often because that is when participants are mentally and physically available for joining research studies), some follow participants longitudinally, during the sub-acute stage or from the sub-acute into the chronic stages of aphasia. Among the cases described above, four participants identified in the literature were assessed during the chronic stage of recovery (Goral, 2012; Kiran & Roberts, 2010, case 1; Kiran et al., 2013, UT17; Meinzer et al., 2007), together with the two participants described from our clinical research (EH02 and EH03). One would expect that their absolute and relative language abilities may be more stable than those assessed during the sub-acute stage of recovery (Filiputti et al., 2002; Kiran & Roberts, 2010, case 2; Knoph et al., 2015; Radman et al., 2016, Subjects 2, 3, 4 and 5). At the same time, post-stroke attrition, due to one language environment being preferred or enforced over another, does not occur immediately after the stroke, but rather language abilities will subtly decline over time. It is not always under the SLT's control whether assessment and/or treatment of multilingual individuals with aphasia occurs during the sub-acute or chronic stage, but outcome expectations in each language will be affected by the amount of time that has passed since the stroke. SLTs should be aware of the implications of working with multilingual individuals with aphasia during the different stages of recovery.

## 4 Conclusion

Post-stroke language abilities in multilingual people with aphasia are a complex outcome of pre-stroke language proficiency, exposure and use, together with the resulting impairment after a brain lesion as well as each person's unique post-stroke communication dynamics of language exposure and use. We recommend gathering information on pre-stroke language proficiencies and use by administering a comprehensive (but not overly detailed) language background questionnaire that includes questions on language exposure and use, identifies peak and overall pre-stroke proficiency, and potential attrition. We further recommend collecting all available information on the brain lesion. Using this knowledge together with data collected in the questionnaire will strongly influence how post-stroke language abilities are interpreted, and in turn help to plan effective treatments. When possible, post-stroke language abilities should be collected from different stages of recovery and compared to each other and to patterns of pre-stroke language proficiency and use. This would allow clinicians and researchers in the future to further disentangle the effects of the brain lesion, spontaneous recovery and direct treatment effects from other post-stroke factors such as exposure and use of each language, as well as pre-stroke factors including proficiency, exposure and use.

Manner of acquisition (i.e., formal vs. informal communication contexts) is another important factor in language development in both monolingual and multilingual individuals (e.g., Ellis, 2009). In the non-native languages of multilingual people, manner of acquisition is related to both AoA and pre-stroke proficiency, and there is merit for future research concerning how different types of treatment (e.g., implicit vs. explicit) are effective on different languages relative to the manner that each language was originally acquired. Another area for future research is considering how age-related language changes interact with attrition, and the effects of both on pre- and post-stroke language abilities. Furthermore, we suggest considering additional sociolinguistic factors that affect language use across multilingual individuals with aphasia, such as language status in the country or community of residence and attitudes towards the languages. These factors are closely related to language environment and likely influence its effects differently across multilingual populations.

Additionally, we hope that more studies will become available that combine specific brain-lesion data with behavioural language data. These studies will increase our knowledge of the influence of the language control network on patterns of impairment in multilingual individuals with aphasia. Furthermore, this will aid future research on how pre-stroke language mixing patterns together with a brain lesion affect post-stroke language mixing patterns and, in turn, the effect on post-stroke language abilities. A better understanding of the influence of the language control network will allow for language mixing to be incorporated appropriately during treatment.

In summary, although assessing and treating multilingual people with aphasia involves taking into account a complex set of factors, by better understanding the contribution of language history, together with a specific brain lesion, to post-stroke language impairment, we can reduce the confusion and be more confident in our conclusions based on post-stroke language assessments.

## Notes

1. It should be noted that, in this case, Hebrew was acquired at one of the Jewish Day Schools in New York. These schools place high importance not only on teaching Hebrew as a second language, but also conducting classes on religious instruction and religious text study only in Hebrew. Therefore, up to half the school day may be taught in, or about, the Hebrew language, resulting in many students acquiring Hebrew to moderate-high proficiency levels.
2. The remaining participant, Subject 1, had damage to medial frontotemporal regions, but it was unclear whether one or both networks were damaged, due to the lesion’s proximity to the subcortical structures – thus we do not report on this participant.

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No potential conflict of interest was reported by the authors.

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