

Review

# Mandarin–English Code-Switching in Aviation Phraseology: A Critical Review of Bilingual Control and Neurocognitive Evidence

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**Abstract:** Mandarin–English code-switching is an underexamined but theoretically informative feature of aviation phraseology. It occurs in a safety-critical communicative ecology that combines standardised formulae, English abbreviations and call signs, Mandarin operational instructions, and frequent bilingual training. This critical review integrates research on aviation communication, bilingual language control, and event-related potentials (ERPs). It distinguishes cross-language code-switching from phraseology–plain-language alternation and evaluates behavioural, ERP, EEG, and MEG evidence on direction asymmetry, switching experience, proficiency, phrase frequency, and domain-general control. Switch costs are neither invariant nor reducible to a single component: early negativities may reflect interference detection or lexical selection, the N400 is sensitive to lexical-semantic prediction and integration, and late positivities can reflect controlled updating or integration. The review also synthesises Chinese–English ERP studies of general lexical and sentence contexts. These studies show that direction and grammatical locus modulate component profiles, clarifying that the critical gap is not the absence of Chinese–English neurocognitive research but the absence of published ERP work using aviation phraseology as critical material. The Adaptive Control Hypothesis, the Control Process Model, and bilingual lexical-access models jointly suggest that aviation expertise and repeated exposure to phraseological units may reshape processing. The review concludes by identifying methodological priorities for a cumulative literature, including the measurement of professional language experience, the separation of phraseological units from isolated switched words, and the integration of behavioural and neurocognitive evidence.

**Keywords:** aviation phraseology; code-switching; bilingual control; neurocognition; bilingualism

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## 1. Introduction

Code-switching—the alternation of two languages within a communicative episode—has long been recognised as both a natural bilingual practice and a demanding psycholinguistic event. In experimental settings, such alternation can slow response times, reduce accuracy, alter eye movement patterns, and elicit reliable electrophysiological differences beginning within the first few hundred milliseconds after a critical word [1–3].

Aviation phraseology provides a particularly valuable setting for examining these effects. Air–ground communication is safety critical, time sensitive, and institutionally regulated. International regulatory frameworks distinguish standardised radiotelephony phraseology from plain language, which is reserved for non-routine situations where standard phrases are insufficient. Aviation English is therefore not ordinary conversational English: it is a highly constrained professional register characterised by fixed lexical sequences, procedural expectations, and restricted grammatical patterns. In

Chinese aviation contexts, routine communication frequently combines Mandarin terms with English letters, abbreviations, aircraft designators, and conventionalized English expressions. This semi-artificial linguistic ecology renders Mandarin–English switching both practically consequential and experimentally tractable [4-9].

This review has four aims. First, it clarifies what constitutes code-switching in aviation communication and distinguishes this phenomenon from related register alternations. Second, it reviews findings from aviation-language research to establish why processing efficiency is essential for safety and training effectiveness. Third, it synthesises behavioural and neurocognitive evidence on bilingual switching, with emphasis on directionality, language experience, domain expertise, predictive processing, and the event-related potential components most consistently observed in empirical studies. Finally, it evaluates the conceptual and methodological implications of this evidence for future research on Mandarin–English aviation phraseology. This is a narrative, theory-driven critical review; it does not claim exhaustive coverage or follow the formal study-selection procedures of a systematic review.

## **2. Aviation Phraseology as a Constrained Bilingual Ecology**

### *2.1. Standard Phraseology, Plain Language, and Multilingual Practice*

The linguistic organisation of aviation communication is often described in terms of a functional distinction. Standard phraseology encodes recurring operational transactions through concise, conventional forms; plain aviation English supports communication when an event is novel, complex, or insufficiently covered by the prescribed repertoire. The distinction is institutionally important because both standardisation and communicative adequacy matter in safety-critical interaction. Aviation language policy has been characterised as involving a highly restricted code rather than general language ability alone. Corpus research further confirms that aviation English has a distinctive multidimensional profile, supporting the view that it should not be treated merely as a topic vocabulary list [4-6,8].

This distinction is relevant to code-switching but should not be conflated with it. Moving from standard phraseology to plain English changes register and procedural predictability even when the language remains English. This phenomenon has been framed as code-switching within Aviation English, whereas linguistic code-switching in the narrower sense involves alternation across identifiable language systems. In the present review, Mandarin–English code-switching refers to alternation between Mandarin and English lexical or phraseological material, while phraseology–plain-language alternation refers to switching between aviation registers. The two processes may recruit overlapping control mechanisms because both require speakers and listeners to revise predictions about the upcoming form and communicative action; they should nevertheless be operationalised separately in experiments [10].

Actual radiotelephony shows that aviation communication is neither wholly uniform nor insulated from local language practice. Deviations from standard phraseology and insertions of local language elements have been observed in air traffic control communication, with workload and workshift associated with patterns of communicative problems. Similar local extensions have been documented in other national contexts. In an Indonesian context, it has been reported that controllers switched to a local language when communicative needs extended beyond the available international phraseology. These studies are primarily descriptive rather than neurocognitive, but they establish an essential point: multilingual and multiregister alternation is an empirical property of aviation communication, not a laboratory fiction [11-13].

For China, the linguistic ecology is especially instructive. Mandarin radiotelephony materials for civilian pilots have been described as combining Mandarin terminology, English letters, and English abbreviations. Chinese descriptions of air–ground language likewise emphasise its semi-artificial, procedural character. Such mixtures do not automatically entail the same mental operations as spontaneous bilingual conversation. A

call sign or English acronym may be learned as a unit within a Mandarin professional routine, whereas an unpredictable switch to an ordinary English lexical item may require online reorientation to a competing language. This distinction motivates a phraseological-unit approach: experimental stimuli should be coded not simply as isolated words but as conventional operational units whose frequency, position, semantic role, and language membership are independently documented [9,14].

Textbook codification is also relevant to this linguistic ecology. Current Chinese civil-aviation teaching materials can help identify conventional phraseological units and contextualise how Mandarin and English resources are presented in formal instruction, while not exhausting the variability of live radiotelephony [15].

### *2.2. Why Aviation Processing Deserves Neurocognitive Study*

The safety imperative for studying aviation language is well established. Miscommunication may result from the combined effects of linguistic complexity, acoustic conditions, cognitive load, and interactional demands. In simulated general aviation environments, increased informational density, elevated task demand, and the absence of prosodic pauses have been associated with higher rates of communication errors, especially among users whose first language is not English. Real-world communication analyses further indicate that regional pronunciation patterns and intricate numerical expressions can hinder accurate comprehension. Recent investigations involving Korean pilots and air traffic controllers highlight challenges related to language proficiency, speech rate, pronunciation variation, and the use of standardised phraseology. These observations collectively underscore that effective operational performance relies on more than static vocabulary knowledge [16-18].

The relevance to Chinese training contexts is direct. Operationally critical elements—including call signs, altitude, heading, frequency, and core action verbs—often involve lexical shifts, abbreviations, or highly conventionalized multi-word units. A language assessment measuring general proficiency may therefore fail to capture how rapidly trainees detect linguistic changes, retrieve domain-specific units, integrate them into ongoing message processing, and select appropriate operational responses. ERP methods are particularly suited to this purpose, as they enable temporal separation of these successive cognitive operations at millisecond resolution.

The practical implications should be carefully calibrated. ERP amplitude measures do not constitute direct indicators of operational safety, and laboratory-observed processing effects cannot be directly equated with real-world risk. Rather, ERP research offers explanatory insight: it helps determine whether observed behavioural difficulty aligns with early attentional monitoring, lexical-semantic integration, or later stages of information updating and reinterpretation. Such distinctions inform training design, as different processing bottlenecks suggest distinct pedagogical strategies. For instance, difficulties arising from unfamiliar abbreviations may be addressed through targeted lexical and phraseological instruction; those linked to switch direction or unexpected linguistic variation may benefit from structured exposure and pattern practice; and those exacerbated by degraded auditory input may require perceptual training and materials reflecting authentic operational conditions.

### *2.3. Aviation Expertise and the Professional Lexicon*

Aviation expertise extends beyond general English proficiency. Repeated exposure to structured forms and stable form–meaning mappings may support a distinctive professional lexicon. Corpus evidence demonstrates the domain-specific nature of radiotelephony vocabulary [19], while behavioural work suggests that familiar specialised items may be processed differently from unfamiliar general-language items [20].

This perspective resonates with research on habitual code-switching communities. Investigations into bilingual language processing reveal that recurrent language switches—particularly those involving prefabricated multi-word units—can develop unit-like cognitive representations, leading to reduced processing costs. Similarly, higher

corpus-estimated frequency of switching has been associated with more efficient real-time sentence comprehension. These observations do not imply universal fluency in all aviation-related language switches. Rather, they support a conditional model of expertise: phraseological units that are high-frequency, operationally predictable, and embedded in trained routines impose lower integration demands on experienced aviation personnel than on individuals lacking comparable professional immersion; conversely, low-frequency, non-routine, or contextually unexpected switches continue to present significant cognitive challenges [21,22].

### **3. Models of Bilingual Switching and Their Relevance to Aviation**

#### *3.1. Inhibitory Control and Adaptive Control*

The Inhibitory Control model proposes that bilingual production involves selecting the intended language while inhibiting competing linguistic representations, with the degree of inhibition influenced by relative language familiarity. Early observations of asymmetric switching costs—often greater when reverting to the more familiar first language—were initially interpreted as indicating stronger inhibition of the more familiar language in mixed-language settings. This production-focused framework is valuable, but it does not directly predict the direction of comprehension-related processing demands. Specifically, its foundational logic would associate greater processing demand with transitions from a less familiar to a more familiar language, rather than the reverse [23, 24].

However, asymmetry in switching costs is not uniquely attributable to one regulatory mechanism. Research has indicated that such patterns observed in naming tasks may reflect multiple underlying processes and should not be assumed to exclusively signal the intensity of inhibitory control. In comprehension, the observed pattern may depend on factors including relative language familiarity, sentence predictability, frequency of exposure, situational context, and task design. Some studies have reported increased processing demand when moving from a more familiar to a less familiar language, while others found balanced demands among highly proficient bilinguals. For Mandarin–English aviation phraseology, therefore, a larger processing demand during Mandarin-to-English comprehension represents an empirically supported possibility—not a necessary inference from production-oriented models. Such variability is theoretically informative, suggesting that language control adjusts dynamically to the user’s communicative environment [25–28].

The Adaptive Control Hypothesis formalises this perspective. It proposes that bilingual language control adjusts according to interactional settings, such as single-language use, alternating-language use, or frequent alternation between languages. Associated regulatory functions include maintaining communicative goals, regulating competing representations, monitoring situational cues, detecting relevant signals, and adjusting planning strategies opportunistically. Aviation communication constitutes a well-defined interactional setting: objectives are precisely specified, participants share standardised procedural knowledge, and linguistic forms are highly constrained. Nevertheless, operational conditions may shift between routine and non-routine states, with language alternations triggered by call signs, standardised abbreviations, or the need to describe events beyond standard phraseological scope [29].

The Adaptive Control Hypothesis serves best as a heuristic for generating testable predictions, not as an established universal principle. Large-scale investigations have yielded inconsistent findings regarding generalised advantages in non-linguistic regulatory functions among bilingual individuals. Rigorous methodological approaches have failed to confirm straightforward links between bilingual interactional experience and enhanced response management. Comprehensive reviews similarly advise against overgeneralising across domains. More targeted evidence remains supportive: certain studies indicate that both language familiarity and experience with language alternation contribute meaningfully to regulatory performance, and other work shows that exposure

to mixed-language input predicts improved adaptation to regulatory demands in tasks involving linguistic or symbolic stimuli. For aviation contexts, the appropriate interpretation is domain-specific regulatory adaptation—not a broad assertion that aviation trainees will demonstrate superior performance across all executive function measures [30-33].

### *3.2. Control Processes and Switching Types*

A control process model distinguishes alternation, insertion, and dense code-switching as interactional patterns that engage distinct cognitive control states. Alternation involves movement between relatively separable language systems; insertion embeds material from one language into a syntactic frame associated with another; dense switching permits more integrated coactivation of linguistic representations. Subsequent behavioural studies have confirmed that switch type influences processing demands, with differential effort observed across types and distinct associations identified between switching patterns and executive control mechanisms [34-36].

This taxonomy holds relevance for aviation communication but requires contextual adaptation. For instance, a call sign incorporating English letters within Mandarin operational syntax may function like insertion; a sequence alternating Mandarin instructions with conventional English phraseological units may reflect alternation; and highly practised bilingual utterances may operate as dense, prefabricated chunks. Formal linguistic classification should not rely solely on surface appearance. Researchers must document the syntactic host language, the functional role of the non-dominant unit, its token frequency in training and operational materials, and whether users perceive it as a conventionalized chunk—features that may better predict processing behaviour than the generic label "switch".

### *3.3. Bilingual Lexical Access and Phraseological Units*

Lexical models provide a complementary explanation. The Bilingual Interactive Activation framework assumes language-nonselective word recognition, with orthographic, phonological, lexical, and language nodes interacting dynamically during recognition. Computational extensions such as the Multilink model account for bilingual word recognition and translation through interconnected lexical representations. From this perspective, a Mandarin–English aviation unit can activate both language membership information and semantic candidates, even when only one language code is task relevant [37-39].

For phraseology, lexical switching and unit recognition may be closely intertwined. A familiar item such as a conventional aviation abbreviation may be accessed rapidly due to its entrenched form-to-meaning mapping, even if its surface form is English. Conversely, a rare English item embedded in Mandarin may incur greater processing cost because its lexical representation is less accessible and its language cue is unexpected. Asymmetric mappings between first and second language lexical and conceptual systems have also been observed, particularly among less balanced bilinguals. This asymmetry offers a plausible basis for direction effects; however, it must be empirically validated using independent measures of general English proficiency and domain-specific aviation phraseology knowledge [40].

## **4. Mandarin–English ERP Evidence and Broader Behavioural Evidence on Code-Switching during Comprehension**

### *4.1. Mandarin–English ERP Evidence and the Aviation-Specific Gap*

The absence of aviation materials from the ERP literature should not be mistaken for an absence of Mandarin–English evidence. A substantial body of research conducted in China has examined sentence-level code-switching in Chinese learners of English, including switches at subject, predicate, and object positions. These studies are important because they demonstrate that the neural signature of a switch is modulated by its grammatical locus and processing direction rather than being reducible to a unitary

"switch cost". In a study of object-position switches, Chen et al. [43] reported that English-to-Chinese switches elicited larger P200 and N400 responses, whereas Chinese-to-English switches elicited larger left anterior negativity (LAN) and late positive complex (LPC) responses. Direction asymmetry was also evident in P200, LAN, and LPC measures. This work provides a direct Mandarin-English precedent for treating early attention-related, lexical-semantic, and late integration-related effects as separable stages of processing [41-43].

Research conducted in China has also extended beyond sentence constituents. One study examined code-switching in a digit parity-judgement task, while another investigated lexical processing in proficient Chinese-English bilinguals. Together with theoretical and methodological reviews, these studies establish that direction asymmetry, task demands, proficiency, and control processes have already been actively debated in the Chinese literature. Recent ERP work in Chinese-English-Japanese trilinguals further demonstrates that these questions remain productive in multilingual settings, although such work should not be treated as interchangeable with Mandarin-English bilingual comprehension [44-49].

The more precise gap is therefore not that Mandarin-English code-switching has received no ERP attention. Rather, the literature reviewed here does not identify a published ERP study in which aviation phraseology constitutes the critical linguistic material. Existing Mandarin-English studies primarily use everyday lexical items or general sentence contexts, and they rarely examine how a constrained professional repertoire, repeated phraseological experience, and safety-relevant communicative expectations jointly shape code-switch processing. Aviation phraseology thus extends, rather than replaces, the existing Mandarin-English literature.

#### *4.2. Behavioural Evidence in Broader Bilingual Comprehension*

Behavioural studies consistently demonstrate that language switches can alter reading time, naming latency, accuracy, and eye movements, though the magnitude and even direction of these effects are conditional. Early work in word recognition found electrophysiological and behavioural evidence that code-switches influence bilingual lexical processing. At the phrase level, switching costs have been observed for proficient Mandarin-English bilinguals, while sublexical contributions to comprehension have also been identified. More recent work has moved beyond establishing whether a cost exists to identifying its underlying sources [1,50,51].

Direction is one major source of variation. In production, asymmetric switching costs are well established in many settings. Comprehension is more complex because the switch can change expectations about both the incoming language and the incoming word. Research has shown that direction affects behavioural, ERP, and time-frequency indices of intra-sentential switching. Further findings indicate that inhibitory control and language proficiency interact dynamically: a cost pattern may change over successive switched words as inhibition is released or reconfigured. Thus, a Mandarin-to-English versus English-to-Mandarin contrast in aviation materials should not be interpreted solely through nominal L1/L2 labels; participants' effective language use patterns, recent language exposure, and local sentence context all matter [24,27,52,53].

Prediction and experience are equally important. Studies have distinguished semantic unexpectancy from language unexpectancy, showing that not all switch effects reflect the same type of surprise. Using self-paced reading, researchers have found dynamic engagement of cognitive control during intra-sentential code-switching comprehension. Converging behavioural evidence indicates that exposure frequency reduces processing costs, while production distributions have been shown to shape comprehension patterns. In aviation, phraseological frequency and prior training may therefore change the prior probability of a switch. A switch that violates everyday conversational expectations may be entirely expected in a familiar operational frame [22,54-56].

Input modality deserves explicit consideration. Aviation communication is predominantly spoken and often acoustically degraded, whereas many bilingual switching experiments use silent visual reading. Relevant investigations into auditory intra-sentential code-switching have found direction-sensitive neural effects. Other studies have demonstrated that bilingual listeners can use phonetic cues preceding a code-switch to anticipate the upcoming language and limit activation of the non-target language. Direct testing of accent and input modality in Mandarin–English bilinguals has revealed robust processing costs, with limited evidence that these factors fundamentally alter language coactivation. The appropriate conclusion is not that modality is irrelevant. Rather, auditory experiments require specific controls for acoustic and speaker-related variables, including talker, speech rate, prosody, intensity, accent, signal quality, and pre-switch phonetic cues. Visual rapid serial visual presentation (RSVP) paradigms retain considerable value for isolating the linguistic mechanism; auditory follow-up work is needed to test the ecological generality of the results [57-59].

## 5. ERP Evidence: From Incongruity Detection to Late Integration

ERP methodology is well suited to the central problem because it captures time-locked neural activity without requiring an overt response at the critical unit. It is also inherently inferential: a component does not map one-to-one onto a single cognitive operation. Interpretation must therefore rest on latency, scalp distribution, task design, and converging behavioural evidence rather than a component label alone [60,61].

### 5.1. Early Negativities: N2/N200 and Incongruity-Related Processing

The N2/N200 is commonly observed as a frontocentral negative-going deflection roughly 150–350 ms after a stimulus, though its precise latency and functional interpretation vary by paradigm. Early left anterior negativities—particularly the left anterior negativity (LAN) and early left anterior negativity (ELAN)—fall within the broader family of early negativities considered here. Reviews associate N2 variation with monitoring of task-relevant discrepancies, mismatch detection, cognitive control, and response inhibition. In language switching, early negativities have been reported in both comprehension and production, but they are not a pure measure of language inhibition. Early switch-related effects have been identified in simultaneous interpreters, while individual differences in domain-general inhibitory capacity have been linked to the degree of non-target-language inhibition in bilingual word production [62-64].

In future aviation-language experiments, an N200 effect at frontal and frontocentral sites should be interpreted conservatively as evidence that a switch or language-incongruent unit is detected early and may recruit monitoring or control processes. A larger N200 for switches than non-switches would be consistent with early detection of task-relevant discrepancies; attenuation among experienced aviation users would be compatible with more efficient or more predictable processing of trained units. Neither result alone would establish inhibition, expertise, or safety relevance. Any such N200 effect needs to be evaluated alongside proficiency and aviation-knowledge measures, behavioural performance, and later components. The absence of a robust N200 would also be theoretically meaningful. Because early effects are highly sensitive to modality, stimulus format, and the degree to which phraseological units have become automatic, an absent effect may reflect stimulus properties rather than a failure of early detection.

### 5.2. N400: Lexical-Semantic Access, Prediction, and Integration

The N400 is a centroparietal negative-going component that reflects sensitivity to semantic expectancy, lexical access, and the degree of fit between a word and its preceding context. In bilingual switching research, a more negative N400 amplitude at a switched item has frequently been interpreted as indicating heightened demands on lexical-semantic integration. The broader N400 literature provides the interpretive background for this component [65]. Foundational switching studies showed that language alternation modulates electrophysiological processing [2,3], and subsequent work demonstrated that grammatical class and sentence position influence switch-related effects [66].

Interpreting the N400 in aviation-related materials requires particular attention. A code switch may be unexpected due to language selection, lexical content, or deviation from established phraseological patterns. Although these sources are interrelated, they are empirically distinguishable. Research has shown that language-related unpredictability and semantic unpredictability can elicit distinct neural responses. Future investigations should therefore equate switched and non-switched items on plausibility, predictability approximating cloze probability where possible, word frequency, length, part of speech, phrase position, and operational meaning. In Mandarin–English materials, script differences introduce an additional factor: visual transitions from Mandarin to English involve orthographic change, whereas auditory stimuli do not. Such modality-specific characteristics do not compromise experimental validity but must be explicitly acknowledged as contributors to the observed effects and ideally examined through cross-modal designs [54,67].

An interaction between aviation expertise and the N400 would yield valuable insights. If trainees exhibit a reduced switch-minus-non-switch N400 difference for highly familiar operational units, this would suggest that domain-specific experience enhances semantic or phraseological integration efficiency. A larger N400 for Mandarin-to-English trials compared with English-to-Mandarin trials could reflect direction-sensitive processing difficulty; however, this should not be assumed to indicate lower second-language proficiency, as the effect may instead stem from phrase frequency, contextual predictability, or response preparation requirements. The most robust interpretation will integrate item-level predictors with group-level comparisons.

#### *5.3. P600/LPC: Reanalysis, Updating, and Controlled Integration*

Late positive components, often reported as the P600 or late positive complex (LPC), are especially prominent in code-switching research. Initially associated with syntactic processing and integration difficulty, the P600 has since been interpreted more broadly. Subsequent work suggests that such effects can arise during the integration of information that challenges an initially constructed interpretation. Further investigation has examined the functional relation between P600-like responses and the P3b component. A late positivity following a language switch may therefore reflect not only grammatical repair but also controlled updating or integration of an unexpected language cue into the developing message representation. This interpretation depends critically on task demands, temporal characteristics, and scalp distribution, rather than being determined solely by the component label [68-70].

Several findings support this broader interpretation. A late positivity has been observed particularly for switches from a stronger to a weaker language. Auditory studies have shown that dominant-to-nondominant switches elicit both N400 and LPC effects, whereas the reverse direction yields a more limited electrophysiological pattern. It has also been demonstrated that the social presence of another person modulates the processing of code-switches, indicating that late integration is sensitive to communicative context rather than language membership alone. Recent ERP evidence further indicates that cognitive control is dynamically engaged during dense code-switching comprehension [27,57,71,72].

For aviation phraseology, a P600/LPC is theoretically relevant because it may capture the point at which an initially detected switch is incorporated into a procedural message. A larger positivity for switches than non-switches would be consistent with controlled updating; a larger Mandarin-to-English effect would align with additional reorientation to less dominant or less expected English material; and a smaller switch effect among experienced aviation users would be compatible with expertise-related processing efficiency. These remain testable hypotheses rather than diagnostic rules. A late positivity can also be modulated by target detection, task relevance, stimulus probability, or the position of the critical unit. Studies in this area must therefore avoid confounding language switches with the sole task-relevant item in a sentence.

#### *5.4. Beyond ERPs: Oscillations and Converging Measures*

Time–frequency analysis can reveal neural activity that is not phase locked to stimulus onset. Previous studies have combined ERP and time–frequency approaches, while others have linked language switching costs in highly proficient bilinguals to alpha desynchronisation and engagement of a frontoparietal network. Similarly, induced oscillatory activity has been found to differentiate language switching between experienced and newly acquired languages. These findings suggest that phase-locked ERP components and induced oscillatory activity may reflect related but distinct aspects of language control [27,28,73].

In future empirical work, ERP analyses should remain primary and preregistered or otherwise specified in advance. Time–frequency analysis is best framed as a theoretically motivated extension, with clearly articulated hypotheses and appropriate correction for multiple comparisons. This hierarchical approach prevents broad exploratory analysis from being misrepresented as confirmatory evidence, while still allowing examination of whether aviation expertise modulates sustained control processes beyond the canonical N200, N400, and P600/LPC time windows [61,74].

## 6. Methodological Implications for Future Research

### 6.1. Key Contrasts and Evidential Priorities

The literature highlights three distinctions that future research should treat separately rather than conflate: language switching versus non-switching contexts, Mandarin-to-English versus English-to-Mandarin transitions, and specialised aviation language experience versus general bilingual proficiency. Studies involving occupational bilinguals should explicitly compare participants with and without relevant phraseological expertise and report direct measures of that expertise; categorical group labels alone are insufficient. Directional effects should be interpreted in relation to individual language proficiency levels, recent language exposure, and the frequency of domain-specific phraseological units, rather than assumed to reflect fixed, language-level properties.

The resulting predictions remain conditional. Language switches may elicit larger N400 and/or P600/LPC responses than non-switches when they violate an active language expectation. Mandarin-to-English transitions may impose greater processing demands for individuals with higher Mandarin proficiency and lower automaticity in English aviation expressions; however, this effect may diminish or invert for highly frequent professional units. Lower switch-related costs among experienced aviation personnel would align with experience-driven improvements in integration efficiency. Conversely, absence of an expertise effect would also yield meaningful insight—potentially indicating that general English proficiency, rather than domain-specific knowledge, underlies processing outcomes, or that the experimental materials fail to adequately represent professional phraseological competence.

### 6.2. Stimulus Construction and Control

The unit of analysis should be the phraseological unit, not merely the individual word. This reflects both the formulaic nature of aviation language and findings that cross-language effects vary with word class, position, and phrase-level context. Materials should be grounded in authoritative sources such as ICAO radiotelephony guidance and Chinese civil-aviation teaching materials, including recent pedagogical resources, and supplemented by corpus-based frequency estimates where available. Each experimental condition should feature operationally plausible messages, and the critical unit should be matched as closely as possible for frequency, length, lexical category, semantic predictability, position, and visual or acoustic properties [4,5,15,66].

Several methodological decisions require explicit justification. When materials are presented visually, script variation constitutes a controlled experimental factor and must be clearly addressed. When presented auditorily, speaker identity, recording fidelity, speech rate, prosody, and signal-to-noise ratio must remain consistent across conditions. Conceptually equivalent messages should be counterbalanced across stimulus lists, and

switch likelihood should be balanced and explicitly reported, as high predictability may reduce the magnitude of observed effects. Researchers must also carefully differentiate genuine cross-language switching from English technical symbols that participants may interpret as conventionalized components within Mandarin phrases.

### 6.3. Participant Characterisation and Expertise

The label "aviation group" is insufficient on its own. Participants' aviation training stage, knowledge of aviation phraseology, general English proficiency, relative use of Mandarin and English, exposure to English radiotelephony, self-reported frequency of language switching, and recent language use should be measured. A brief objective bilingual test of aviation terminology is particularly valuable because it distinguishes professional knowledge from self-report. These measures can be analysed as continuous predictors or used to document the intended contrast in expertise.

This characterisation matters because expertise is multidimensional. An aviation student may know standard forms well but have limited experience with non-routine plain language; a non-aviation participant may have high general English proficiency but lack phraseological knowledge. The group comparison should therefore be interpreted as reflecting differences in professional learning histories rather than inherent distinctions between individuals. The approach aligns with frameworks emphasising experiential development and is supported by evidence indicating that language control is influenced by proficiency level, cultural background, and interactional practice [75-77].

### 6.4. EEG Preprocessing, Analysis, and Reporting

High-quality ERP inference depends on transparent preprocessing and analysis. Standard practice includes applying frequency filters appropriate to the research question, segmenting data into epochs time-locked to the critical phraseological unit, performing baseline correction, re-referencing the signal, and systematically identifying ocular and other non-neural artefacts; the number of retained trials per experimental condition must be explicitly reported. Widely adopted analysis environments support these procedures, and independent component analysis-based methods can assist in artefact correction when underlying assumptions and rejection criteria are rigorously defined [78-81].

For a priori ERP analyses, frontal and central electrode regions are typically selected for N200 components, while centroparietal regions are used for N400 and P600/LPC components; time windows should be justified by established literature and empirical inspection of the data—not selected *post hoc* to enhance statistical significance. Cluster-based permutation tests offer a valuable complementary approach, mitigating arbitrariness in electrode and time-point selection while effectively controlling for multiple comparisons. Behavioural outcomes and single-trial ERP measures may also be analysed using mixed-effects models that jointly account for variability across participants and experimental items. The guiding principle is convergence: theoretical interpretations gain robustness when effects across accuracy, response time, component topography, and item-level predictors show consistent patterns [61,74,82,83].

## 7. Limitations and Future Directions

The current evidence base has limitations that should be explicit. First, most laboratory experiments do not reproduce a live cockpit or control-tower environment. They cannot simultaneously capture radio noise, workload, turn-taking, time-critical communication, and multimodal operational demands. Their value lies instead in isolating the neurocognitive consequences of controlled language transitions. Ecological extensions should include recorded radiotelephony, accent variation, noise, and task pressure, informed by research on speech recognition under adverse conditions [84].

Second, code-switching is heterogeneous. An English acronym within a Mandarin instruction, a complete English phraseological unit, and a sudden move from Mandarin to plain English may all be classified as switches but may recruit different representations and control demands. Researchers should report the linguistic status of each material type and avoid generalising from one type to all bilingual mixing. Third, direction labels such

as Mandarin-to-English are approximations. Their interpretation depends on proficiency, relative language use frequency, and experience; they should be supplemented by direct individual-difference measures.

Finally, expertise effects must not be confused with immutable group differences. Training history, frequency of phraseological exposure, and professional identity are plausible mechanisms, but causal claims about training would require longitudinal or structured practice studies. A particularly promising next step would be to assess trainees before and after structured practice with bilingual aviation phraseological units and examine whether behavioural changes are accompanied by changes in N400 or late-positive switch effects. Such work could connect basic models of adaptive bilingual control with evidence-based aviation language pedagogy.

## 8. Conclusion

Mandarin–English aviation phraseology offers a distinctive window on bilingual language control. It is sufficiently constrained to permit rigorous experimental control, yet sufficiently authentic to raise questions that general-language paradigms cannot address. Evidence indicates that switch effects reflect a sequence of potentially separable processes: early detection or monitoring, lexical-semantic access and prediction, and later controlled integration or updating. Their magnitude depends on direction, proficiency, frequency, switch type, modality, and prior bilingual experience.

The central value of ERP research in this domain therefore lies not in merely demonstrating that a switch is "hard" but in identifying when in the processing stream a Mandarin–English aviation transition becomes costly and whether specialised learning alters that trajectory. By integrating aviation-communication research with bilingual-control theory and carefully controlled neurocognitive methods, future work can advance both the cognitive science of code-switching and the evidence base for aviation-language instruction.

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