The computation and effects of air traffic control message complexity and message length on pilot readback performance

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Abstract

Ten years ago a comprehensive analysis quantified the types and frequency of air traffic control (ATC) communications. This submission briefly describes the computation of ATC message complexity, message length and their effects on pilot readback performance. Pilots experienced more difficulty reading back high complexity messages when on approach as compared to departure and the effects of message length were apparent only during approach.

Introduction

Humans are limited in the amount of information that they can effectively process, store, recognize, and recall. We gradually learn to organize sound into progressively larger groups by translating them into a verbal code [1]. As speech enters into verbal working memory (VWM) acoustically relevant sounds are extracted and encoded into phonemes that form syllables that are assembled to create words, phrases, clauses, and other constituents. These representations must be maintained in an active state (rehearsed) otherwise decay begins in about 2 s [2] or they are overwritten by new information. If the upper limit of VWM exceeds 5-7 chunks, problems may occur.

An utterance's complexity can be derived from the amount of information expressed in its constituents measured by the number of words, syntactic nodes, or phrasal nodes [3]. Utterances that exceed VWM capacity impose problems to listeners. The communication exchange between air traffic controllers and pilots is an excellent example.

In the US, air traffic controllers use a rigid set of words/phrases [4] to construct the messages they send to pilots who then read them back. During readback, controllers actively listen for accurate reproductions of the communication elements (CE) comprising their original messages. The presence of a mistake is a readback error (RBE).

ATC messages can contain multiple (CEs). Some words/ phrases serve as anchors that make a (CE) more precise in its interpretation. For example, "3-5-0" is ambiguous until it appears with an anchor — it can be interpreted as a heading, altitude, or speed. Thus degrees are associated with heading, knots with speed and descend/climb with altitude.

A complexity value (CV) is assigned to each anchor, numerical value, orientation (left, right, center), etc. according to the controller's phraseology usage. Furthermore, CV with larger values reflect the added complexity imposed by CEs with more information. To illustrate, 'three thousand five hundred,' 'one-zero thousand' and 'four thousand' most likely impose quantitatively different loads on VWM because 'three thousand five hundred' takes longer to pronounce and contains more words than 'four thousand' (e.g., articulatory loop [5]) and utilizes more capacity [1].

Methods

Audiotapes

Five US TRACON facilities provided a total of 28 hr 13 min 23 s of approach and 23 hr 56 min 32 s of departure communications.

Computing complexity

Each transmission was first parsed into CEs, labeled by speech act category and AT using the procedures developed by [6]. A CV was assigned to a) instructions/clearances speech acts that involved heading, heading modifier, altitude, altitude restriction, speed, approach/departure, frequency, route, and transponder ATs, b) advisory speech act that involved traffic and c) the altimeter portion of weather advisories.

Readback errors

A RBE is as an unsuccessful attempt by a pilot to repeat correctly the information transmitted by ATC. For example, ATC might transmit, "United Ten turn left heading two one zero." If the pilot read back either "three one zero" or "three six zero," it was coded as a substitution error since the numbers in the original heading included neither a three nor a six. If read back as "one two zero" it was coded as a transposition error since the correct numbers were spoken in an order different from the original. The absence of a number during readback was coded as an omission.

Results

Each readback was evaluated for accuracy and the number of errors recorded (e.g., a zero indicated no error while a value of 3 indicated 3 errors). There were 723 RBEs present in 688 pilot transmissions that were derived from 11,159 ATC transmissions. For the 6.2% faulty readbacks, 654 contained 1 error and another 34 contained 2 or more errors. Statistical significance was evaluated with $\alpha \leq .05$.

Message complexity

See Figure 1. Each ATC message was classified as either low ($\leq$ 09) or high ($\geq$10) complexity, paired with its readback, and mean RBE computed for each aircraft. A Sector (Approach, Departure) by Message Complexity (Low, High) ANOVA revealed that pilots produced more RBEs in an approach (Mean = .13) compared with a departure (Mean = .04) sector, [F(1,3700) = 129.00]. Also, more complex ATC messages had more RBEs (Mean = .17) than less complex messages (Mean = .04), [F1,3700) = 154.39]. There were more RBEs for approach high-complexity messages than departure high-complexity messages or low-complexity.

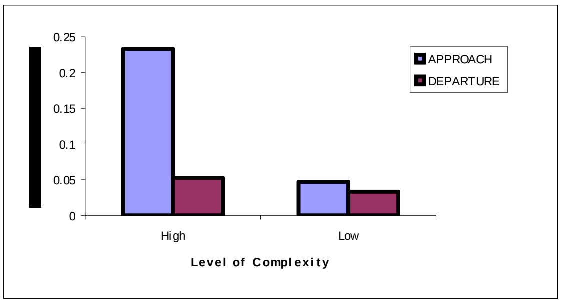

Figure 1. RBEs by sector and message complexity

Message length

See Figure 2. The results of the Sector (Approach, Departure) by Message Length (1AT, 2AT, 3AT, 4AT) ANOVA revealed more RBEs occurred when pilots were in the approach (Mean = .11), as compared with departure sectors (Mean = .03), [F(1,5599) = 78.48].

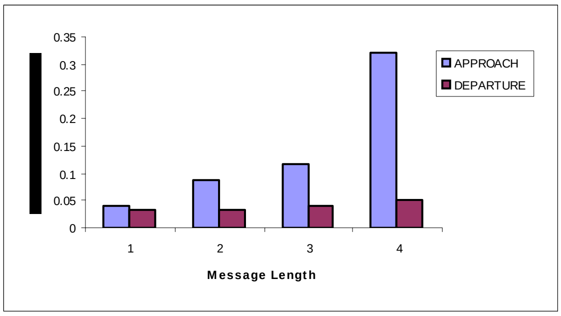

Figure 2. RBEs by sector and message length

The number of readback errors varied with the number of ATs, [F(3,5599) = 21.62]. The fewest readback errors occurred when ATC messages contained one AT (Mean = .04), no difference between messages with 2 or 3 ATs (2AT = .06; 3AT = .08), and messages with 4 ATs contained the most readback errors (Mean = .30). Figure 2 shows that as approach messages increased from one to between 2 and 3 ATs and 4 ATs the mean number of RBEs increased accordingly, [F(3,5599) = 21.62]. The effect of message length was apparent only for approach control.

Discussion

Whether by human or avionics, the accurate transmittal and receipt of information is necessary but not sufficient for communication to occur. Pilots and controllers, the human factors, must acknowledge or otherwise confirm that a common ground of understanding occurred between the source and its intended pilot recipient.

ATC message complexity and length can contribute to the vulnerability of pilot memory. The results provide evidence that RBEs may increase with increases in complexity and message length. Of particular interest was the finding that pilots experienced the most difficulty reading back ATC messages during the approach segment of their flight. Adding to their workload was the read back of a message with more than one AT or a complexity value ≥ 10 as evidenced by increased RBEs.

References

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