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Response to Letter to the Editor: "Nomenclature for real-time magnetic resonance imaging"

A recent Letter to the Editor (Dietz et al MRM 81(5), Nov 2018)[1] raises issues with the use of the "*real-time*" nomenclature in the MRI literature and the under-reporting of reconstruction latency. As a researcher in this field, I would like to express agreement with the importance of reporting latency, while disagreeing with the need for a change in nomenclature.

1 | CURRENT NOMENCLATURE

Figure 1 contains a Venn diagram of current nomenclature and their criteria. The broadest term "*dynamic*" is used for imaging of dynamic processes (e.g., cardiac function) with adequate temporal resolution to resolve the dynamics. This often involves repetition of a movement with synchronized acquisition, known as gating. The term "*real-time*" is used for dynamic imaging without the need for repetition (e.g., dynamic contrast enhanced imaging). The term "*real-time interactive*" is used for real-time imaging with low latency (e.g., interactive localization, or interventional guidance). The term "*interactive*" was first used in MRI papers 25 to 30 years ago, when substantial engineering was required to accomplish latencies of less than a few seconds.[2-4] Many authors since then have used "*real-time*" (without "*interactive*") even when their methods provided a high degree of interaction.

Dietz et al argue that the term real-time should be reserved for techniques that provide very low latency and that dynamic should be used when this criterion is not met. I disagree for two reasons. First, this would be inconsistent with colloquial nontechnical use of real-time, which includes live broadcast television that provides ~24 frames per second, latency >2 seconds (sometimes longer to allow for content blocking), and no interaction. Second, this would introduce a new problem of efficiently differentiating methods that do versus those that do not rely on gating (repetitions and synchronization). MRI methods that eliminate the need for gating involve substantial engineering and broaden the scope of MRI applications. Without this capability, it would not be possible to image cardiac function in the setting of arrhythmia, natural speech, or other aperiodic movements. This capability adds substantial value even in the absence of a low-latency online reconstruction and is worthy of the distinct term.

2 | LATENCY REQUIREMENTS

Latency is an important performance measure that merits attention. Our team defines latency as total time between when a pose occurs and when a digital representation is available to the scan operator. Latency requirements are application specific, typically in the range of 100 to 500 ms, and can be determined through dedicated investigation. For example, early telephony experiments found that latency <200 ms is needed for spoken language communication.[5] And, early experiments with the da Vinci robot found that latency <330 ms was required for telesurgery.[6] MRI researchers often infer latency requirements from the literature or rely on their direct experiences. I concur with Dietz et al that end-to-end latency should be reported as a matter of standard practice and that online versus offline reconstruction should be explicitly stated. There are, however, a few nuances.

First, we should welcome works that demonstrate feasibility of online real-time reconstruction even if not overtly realized by the authors. Suppose an author can demonstrate an acquisition frame rate of 10 frames per second, with a reconstruction latency of 1 second using a single processor. That should be accepted as feasibility of online reconstruction (with 10 frames per second and 1-second latency), assuming the load were distributed across 10 processors, even if the authors do not have the resources to purchase 10 processors for the demonstration. This is not an over-reach and will make our field more inclusive.

Second, we should understand that acquired data are often reconstructed in different ways for different goals. Real-time cardiac MRI data may be processed by two reconstruction procedures—one with a low-latency but low quality, which is used to identify and react quickly if the subject develops an arrhythmia or has an adverse event, and the second with a high-latency and high quality, which is used clinically, for example, to evaluate wall motion, ejection fraction, etc. Similarly, real-time speech MRI may be processed by two reconstructions—one with low latency and low quality to

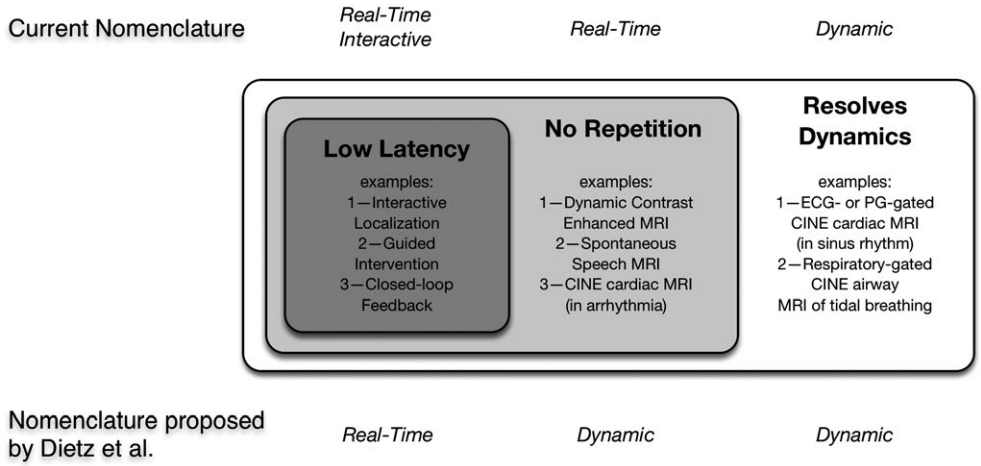

FIGURE 1 Illustration of current nomenclature and key features. *Real-time Interactive* is a subset of *Real-Time*, which is a subset of *Dynamic*. The key feature of dynamic MRI is that it achieves adequate temporal resolution to resolve the dynamic process. The key feature of real-time MRI is that it does so without requiring any repetitions or synchronization. The key feature of real-time interactive MRI is that it does so with low latency, where the specific latency requirements are dictated by the application. The nomenclature proposed by Dietz et al is shown at the bottom. Were it to be adopted, this would require additional language to differentiate methods that do vs do not rely on repetition and/or synchronization

ensure compliance with the stimulus and rule out head motion, and the second with high latency and high quality that is used for detailed analysis of articulator dynamics. This is what often happens in practice.

3 | SUMMARY

In summary, I applaud the discussion of this nomenclature issue and the attention to latency. Words matter, and our field stands to benefit from the many perspectives it brings to bear on developing optimal and scientifically illuminating nomenclature.

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Krishna S. Nayak
Ming Hsieh Department of Electrical and Computer Engineering, University of Southern California, Los Angeles, California

Correspondence
Krishna S. Nayak, University of Southern California, 3740 McClintock Avenue, EEB 400C, Los Angeles, CA 90089-2564.
Email: knayak@usc.edu

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