Effect of MicroMLxS Designated Programmable Audio Input (DPAI) and Switch Settings on FM- and Muted-FM Transparency for Six DPAI Hearing Instruments

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The first purpose of this study was to evaluate the effect of FM receiver setting (DPAI-yes/2-dot, DPAI-yes/1-dot, DPAI-no/2-dot, DPAI-no/1-dot) on FM transparency, measured as FM offset (in dB), for each of six Designated Programmable Audio Input (DPAI) hearing instruments coupled to one Phonak MicroMLxS FM receiver and one Campus-Sx FM transmitter. The second purpose was to assess the effect of muting the FM microphone (i.e., muted-FM transparency, measured as muted-FM offset, in dB) for each hearing aid and DPAI/dot setting. The results indicated that for five of the six aids, mean three-frequency average (750, 1000, 2000 Hz) FM offset was within FM transparency tolerances (American Academy of Audiology, 2008b) for the DPAI-yes/2-dot, DPAI-yes/1-dot, and DPAI-no/1-dot conditions, but exceeded tolerances for the DPAI-no/2-dot condition. For the sixth hearing instrument, mean three-frequency average FM offset was within tolerances for each DPAI/dot condition. The data of the present study also indicated that mean three-frequency average muted-FM offset was within transparency tolerances for all aids in all DPAI/dot conditions. Implications of these data for FM system management in the schools are discussed.

Introduction

Frequency modulation (FM) systems are often recommended to improve the listener signal-to-noise ratio (SNR) for students who are in learning environments characterized by excessive background noise, reverberation, and/or speaker-to-listener distance. The improvement in listener SNR, and associated improvement in speech recognition performance, is due to the placement of a remote microphone close to the target sound source where the level of the signal is high, relative to background noise, and the negative effects of speaker-to-listener distance and reverberation are minimized (Finitzo-Hieber, & Tillman, 1978; Hawkins, 1984; Lewis, Crandell, Valente & Horn, 2004; Pittman, Lewis, Hoover & Stelmachowicz, 1999). The target signal is broadcast from the remote location as an FM radio signal, picked up and demodulated by an FM receiver, and in the case of an ear-level FM system, delivered to a listener's ear through a hearing aid (HA) or other ear-level sound delivery device.

In the classroom, and when coupled to personal hearing aids, ear-level FM systems are recommended to be used in the HA+FM listening mode with an FM advantage setting of at least +10 dB, where both the FM and HA microphones are active and the FM signal is delivered to the listener at 10 dB or more above the signal level provided by the hearing aid microphone (American Academy of Audiology, 2008a, 2008b; American Speech-Language-Hearing Association, 2002). In this way, a student may hear her own voice and the voices of classmates (by way of her hearing aids), as well as having improved access to the teacher's spoken messages (via the FM microphone). Most current FM systems also include a mute function where the FM transmitter remains active, but its microphone is temporarily taken off-line. This function is for those times when the teacher is not providing direct instruction, but the student needs continued auditory access to the class.

The Phonak MicroMLxS FM Receiver

The Phonak MicroMLxS is an ear-level FM receiver that couples to the direct audio input (DAI) of most behind-the-ear (BTE) hearing aids via an audioshoe. The factory-default FM advantage setting for the MicroMLxS is +10 dB (range = -6 to +24 dB), which is designed to result in a 75 dB SPL equivalent-input signal delivered to the DAI of the hearing aid (Platz, 2004). The MicroMLxS FM receiver may be used with each of two types of hearing instruments currently used in the schools: 1) those that employ Designated Programmable Audio Input (DPAI) for FM signals (i.e., DPAI-yes or DPAI-HAs) and 2) those that do not (i.e., DPAI-no or non-DPAI HAs; Platz, 2004). DPAI-HAs generally have an FM and/or FM+M program that must be activated within the hearing instrument for FM use. As part of this design, these instruments have a separate adjustable pre-amplifier for each input channel (e.g., environmental microphone, FM). In contrast, non-DPAI instruments do not have FM or FM+M programs. Instead, FM signals are connected in parallel to the hearing instrument's microphone. This architectural difference is important because when FM is connected in parallel to a hearing

Figure 1. MicroMLxS DPAI setting (courtesy of Phonak).

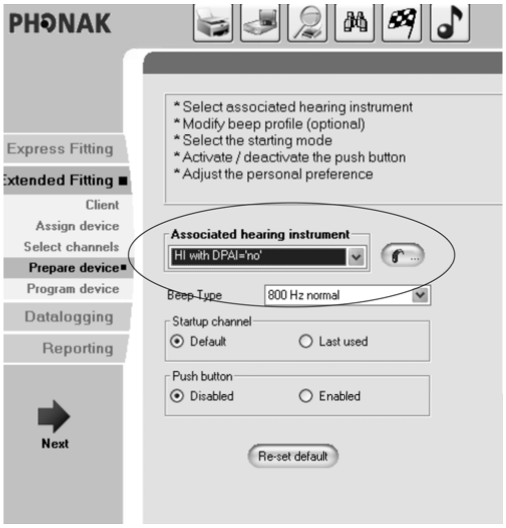
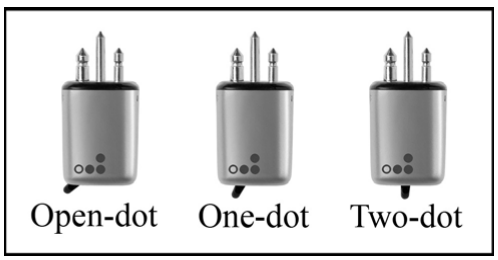


Figure 2. MicroMLxS switch position settings (courtesy of Phonak).



instrument's microphone (as in the case of non-DPAI instruments), the impedance of the FM signal can affect the performance of the HA microphone. When FM signals are connected by way of a separate input channel (as in the case of DPAI instruments), FM signal impedance does not affect the performance of the hearing instrument's microphone.

For either HA design, two MicroMLxS settings are important to the proper function of the coupled system: (1) the DPAI setting, and (2) the external switch setting. The MicroMLxS DPAI setting is accessed via the manufacturer's software, and may be set by the educational audiologist to "Hearing Instrument with DPAI = yes" or "Hearing Instrument with DPAI = no" (factory default; see Figure 1). The MicroMLxS external switch setting is manually set by the audiologist (or user) to "one (closed)-dot" or "two (closed)-dot" for FM listening or "open-dot" for HA-only listening (Figure 2).

Together, the DPAI and external switch settings of the MicroMLxS affect the impedance of the FM signal delivered to the hearing instrument, which in turn affects the listening experience for the student. For non-DPAI hearing aids used with a MicroMLxS at factory defaults, HA+FM listening is determined by the MicroMLxS external switch setting. In the one-dot setting, the FM signal is delivered to the HA with low impedance, which has the effect of muting the HA microphone and results in FM-only listening. Changing the MicroMLxS to the two-dot setting changes the FM from a low to high impedance signal, which has the effect of allowing the FM and HA microphone signals to both be processed by the hearing instrument and results in HA+FM listening (Platz, 2004; R. Platz, personal communication, September 27, 2007).

In contrast, for DPAI hearing aids, HA+FM listening is not determined by the MicroMLxS external switch setting, but by the selection of an appropriate program for FM listening within the hearing aid. When these hearing instruments are coupled to a MicroMLxS at factory default settings, changing the MicroMLxS switch from the one- to two-dot setting does not mute/unmute the HA microphone as FM signal impedance does not affect DPAI-HA microphone performance. Although FM signal impedance does not alter DPAI-HA microphone performance, it does affect the level of the FM signal itself and thus can alter the FM advantage provided by the HA+FM system. Specifically, when the MicroMLxS is set to DPAI-no/2-dot and used with a DPAI hearing aid, the resulting high impedance FM output can result in an FM signal that is as much as 10-15 dB above target (Platz, 2004; R. Platz, personal communication, September 27, 2007).

Importantly, the MicroMLxS DPAI setting serves to activate/deactivate the impedance difference between the one- and two-dot external switch settings. Specifically, when the MicroMLxS is set to "Hearing Instrument with DPAI = no," the one- and two-dot settings result in contrasting FM signal impedances (as above). When the MicroMLxS is set to "Hearing Instrument with DPAI = yes," the resulting FM signal is of low impedance for both the one- and two-dot switch settings. Thus, the MicroMLxS settings of DPAI-yes/2-dot, DPAI-yes/1-dot, and DPAI-no/1-dot are each reported to result in a low-impedance FM signal (R. Platz, personal communication, September 27, 2007). The relative FM-signal impedance resulting from each DPAI/dot setting combinations for the MicroMLxS receiver are summarized in Table 1 below.

Table 1. Relative FM-signal impedance as a function of MicroMLxS DPAI and dot setting.

		DPAI Setting	
		"HI with DPAI = yes"	"HI with DPAI = no"
Switch Setting	"One-dot"	Low FM Impedance	Low FM Impedance
	"Two-dot"	Low FM Impedance	High FM Impedance

Electroacoustic verification of FM transparency. Verification of the performance of a HA+FM system is important to ensure that the target FM advantage is achieved for a listener (American Academy of Audiology, 2008a; American Speech-Language-Hearing Association, 2002; Schafer, Thibodeau, Whalen & Overson, 2007) and may be accomplished by way of an electroacoustic assessment of FM transparency. FM transparency is defined as the condition in which inputs of 65 dB SPL to both the FM and HA microphones of a HA+FM system result in equal outputs from the hearing instrument (American Academy of Audiology, 2008b). If hearing instrument output is not equal for equal inputs to the HA and FM microphones, the resulting output difference (as FM offset, in dB; Platz, 2004, 2006) represents the error in the FM advantage provided by the HA+FM system. For example, if transparency is achieved (e.g., FM offset = 0 dB), then it is assumed that the FM advantage setting programmed into the FM receiver (e.g., +10 dB) results in the expected corresponding level of the FM signal at the DAI of the hearing instrument (e.g., 75 dB SPL equivalent). If hearing instrument output is not equal in a test of transparency (e.g., FM offset = +4 dB), then it is assumed that the FM signal at the DAI of the hearing instrument reflects this offset (e.g., 79 dB SPL equivalent-input).

The American Academy of Audiology (2008b) recommends verifying FM transparency by calculating the average FM offset for the HA+FM coupled system at 750, 1000, and 2000 Hz. In addition, it is recommended that the FM advantage setting of an FM receiver be reprogrammed to correct for non-transparency when FM offset is ≥ 2 dB or ≤ -2 dB (e.g., new FM advantage setting = +6 dB re: +4 dB FM offset, for the above example). Three-frequency average FM offset values < 2 dB and > -2 dB (i.e., within +/- 2 dB) are considered within transparency tolerances.

Consistent with the American Academy of Audiology (2008b) FM electroacoustic verification of FM protocol, an evaluation of HA+FM transparency may also include assessing the effect on hearing instrument output of muting the FM microphone of a HA+FM coupled system. Thus, muted-FM transparency may be defined as the condition in which inputs of 65 dB SPL to the HA microphone of a HA+FM coupled system and to the microphone of the HA alone result in equal outputs. Here, output differences (as muted FM-offset values, in dB) would represent the change in hearing instrument output associated with the coupling of the muted FM system. Currently, the recommendation for evaluating such an effect is to calculate the average muted-FM offset at 750, 1000, and 2000 Hz and note any offset from 0 dB (American Academy of Audiology, 2008b).

Purpose of the Present Study

Although the reported design characteristics of the MicroMLxS FM receiver suggest that educational audiologists have three receiver-setting alternatives when coupling this FM receiver to a DPAI hearing aid (i.e., DPAI-yes/2-dot, DPAI-yes/1-dot, and DPAI-no/1-dot), and that a fourth (i.e., DPAI-no/2-dot) can result in much higher FM signal levels, data comparing system performance across MicroMLxS settings for various hearing instruments are not available in the literature. Therefore, the first purpose of this study was to evaluate the effect of FM receiver settings on FM transparency (as FM offset, in dB) for each of six DPAI hearing instruments coupled to one Phonak MicroMLxS FM receiver and one Campus-Sx FM transmitter.

Likewise, due to a lack of performance data available in the literature, the second purpose of this study was to assess the effect of muting the FM microphone (i.e., muted-FM transparency, measured as muted-FM offset, in dB) for each hearing aid in each FM receiver setting. Although by design, the coupling of a muted FM microphone should not affect the frequency response of an associated hearing aid to an environmental-microphone input, such performance data for the MicroMLxS are not currently available in the literature. Thus, the overall goal of this study was to evaluate, for each hearing instrument, the appropriateness of each DPAI/dot FM receiver setting combination for HA+FM classroom listening under the conditions of the FM microphone being active as well as muted.

Method

Equipment

Six new behind-the-ear (BTE) hearing aids and associated audioshoes were ordered from the manufacturer: (1) Phonak Una M, (2) Phonak Eleva 211 dAZ, (3) Phonak Savia 111 dSZ, (4) Unitron Conversa NT, (5) Unitron Element 4, and (6) Unitron Element 8. Electroacoustic analyses of these instruments confirmed that each met American National Standards Institute ANSI S3.22-2003 specifications (American National Standards Institute, 2003). In addition, a new Phonak Campus Sx FM transmitter (lapel microphone) and a new MicroMLxS FM receiver were ordered from the manufacturer.

Each hearing aid was programmed to "first fit" for a sloping mild to moderate sensorineural hearing loss (250 Hz: 25 dB HL, 500 Hz: 30 dB HL, 1000 Hz: 40 dB HL, 2000 Hz: 50 dB HL, 4000 Hz: 55 dB HL, 8000 Hz: 55 dB HL) using the manufacturer's software (iPFG Successware v2.1 for the Phonak instruments, U:fit v1.4.2 for Element 4 and 8, and Unifit v5.5 for the Conversa NT). FM+Mic was selected as the default start-up (Phonak) or only (Unitron) program. In addition, volume control and toggle buttons, feedback manager, and noise reduction were set to "off." The highest acclimatization level was chosen, and regular tubing and a medium vent were selected for each instrument.

The MicroMLxS DPAI and FM advantage settings were accessed using the Phonak FM programming interface unit and

Phonak FM Successware v3.5. A desktop Audioscan Verifit (model VF1; software v2.8.13) was used to complete all hearing aid measurements. A portable Audioscan Verifit (model RM500SL) was used as a second soundproof test chamber. A Quest Sound Level Meter (model 2400) was used to perform sound level measurements of ambient noise in the testing room.

Procedure

HA+FM system performance was assessed using a procedure based on the American Academy of Audiology (2008b) protocol for the electroacoustic verification of ear-level FM. Specifically, for each hearing aid in each DPAI/dot condition, three electroacoustic HA assessments using a 65 dB SPL calibrated speech input were completed in the following order: (1) $EHA65_{SPL}$[1], (2) $EHA/FM65_{SPL}$, and (3) $EFM/HA65_{SPL.}$ For the first assessment, $EHA65_{SPL}$, the hearing aid was attached to the desktop Verifit's HA-2 coupler and placed inside the test chamber with the hearing aid microphone within 2mm of the reference microphone. The test chamber was closed and a frequency response was generated using a 65 dB SPL standard speech signal.

For the second assessment, $EHA/FM65_{SPL}$, the MicroMLxS receiver was coupled to the hearing aid[2] and placed inside the test chamber with the hearing aid microphone within 2mm of the reference microphone. The Campus-Sx FM transmitter was turned on with the microphone muted; it was set off to the side. The test chamber was closed and a frequency response was generated using a 65 dB SPL standard speech signal. For the third assessment, $EFM/HA65_{SPL}$, the hearing aid, still coupled to the HA-2 coupler, was removed from the test chamber of the desktop Verifit and placed in the test chamber of the portable Verifit. This second test chamber was closed. The Campus-Sx transmitter microphone was set to the omnidirectional mode and placed inside the test chamber of the desktop Verifit within 2mm of the reference microphone. The test chamber was closed and a frequency response was generated using a 65 dB SPL standard speech signal.

All electroacoustic assessments were conducted in a hearing aid fitting room in a university audiology clinic. A sound level measurement of ambient room noise was taken prior to each of the three electroacoustic hearing aid assessments to ensure background noise levels during testing did not exceed 40 dBA. The Campus-Sx FM transmitter was charged for 24 hours prior to data collection. A new hearing aid battery was used for each aid in each DPAI/dot condition, which were completed in the following order: DPAI-yes/2-dot, DPAI-yes/1-dot, DPAI-no/2-dot, DPAI-no/1-dot. Prior to the initial data collection run for each aid in each DPAI/dot condition, the FM advantage setting of the FM receiver was confirmed as +10 dB, and listening checks of the HA alone and the HA+FM system were completed. Good sound quality was noted for all aids in all conditions with the exception of the Conversa NT, where FM signals were found to be noisy/mixed with static. Contact with the manufacturer revealed that FM signals for this instrument are processed via the aid's telecoil, and it was confirmed that the instrument was performing according to specifications (personal communication, J. Dossin, October, 2008).

From the three electroacoustic assessments, two sets of difference scores were calculated for each hearing aid in each DPAI/dot condition, 250—4000 Hz: (1) $EFM/HA65_{SPL}$ - $EHA/FM65_{SPL}$, and (2) $EHA/FM65_{SPL}$ - $EHA65_{SPL}$. The first equation compares hearing instrument output for a 65 dB SPL FM-microphone input ($EFM/HA65_{SPL}$) and a 65 dB SPL HA-microphone input ($EHA/FM65_{SPL}$). These output differences (as FM offset values, in dB) represent the error in the FM advantage of the HA+FM coupled system. The second equation compares hearing aid output for a 65 dB SPL HA-microphone input ($EHA/FM65_{SPL}$) to HA output for 65 dB SPL HA-microphone input ($EHA65_{SPL}$). Here, output differences (as muted-FM offset values, in dB) represent the effect on hearing aid output due to the coupling of the muted FM microphone, as compared to the performance of the hearing instrument alone. The three electroacoustic HA assessments ($EHA65_{SPL}$, $EHA/FM65_{SPL}$, $EFM/HA65_{SPL}$) and associated FM offset and muted-FM offset calculations were repeated six times for each hearing aid in each DPAI/dot receiver condition. Mean data were used for analysis.

Reliability

A second trained individual independently completed one $EHA65_{SPL}$, $EHA/FM65_{SPL}$, and $EFM/HA65_{SPL}$ electroacoustic assessment for each hearing instrument in each DPAI/dot condition, 250—4000 Hz. From these data, FM offset and muted-FM offset values were calculated and compared to the original experimenter's results. For FM offset by hearing instrument, the mean difference between the first and second examiner's values were: Una = 0.08 dB (sd = 0.58 dB), Eleva = 0.30 dB (sd = 0.51 dB), Savia = 0.24 dB (sd = 0.53 dB), Conversa NT = -0.10 dB (sd = 0.61 dB), Element 4 = -0.15 dB (sd = 0.51 dB), Element 8 = -0.35 dB (sd = 0.75 dB). For muted-FM offset (by hearing instrument), the mean difference between the first and second examiner's values were: Una = 0.01 dB (sd = 0.45 dB), Eleva = -0.29 dB (sd = 0.45 dB), Savia = 0.02 dB (sd = 0.58 dB), Conversa NT = -0.24 dB (sd = 0.59 dB), Element 4 = 0.11 dB (sd = 0.66 dB), Element 8 = 0.03 dB (sd = 0.64 dB).

[1] Using the AAA (2008b) terminology: E = electroacoustic evaluation, HA = hearing aid only, HA/FM = input to the hearing aid microphone with the hearing aid and coupled FM system in the HA+FM mode, FM/HA = input to the FM microphone with the hearing aid and coupled FM system in the HA+FM mode, 65_{SPL} = 65 dB SPL input.

[2] For the Phonak instruments, this coupling was via the addition of a separate audioshoe; for the Unitron instruments, the audioshoes were integrated into the hearing aid battery door.

Results

FM Offset

Table 2 displays mean FM offset by frequency, 250—4000 Hz, as a function of MicroMLxS setting for the Eleva, Savia, and Una instruments. As may be seen by Table 2, mean FM offset values for each hearing instrument ranged from -3.33 — 6.5 dB, from -2.17 — 9.0 dB, and from -2.33 — 6.83 dB for the Eleva, Savia, and Una, respectively. Mean FM offset values by FM receiver setting for these three hearing instruments ranged from -3.33 — 0.83 dB for the DPAI-yes/2-dot, from -2.83 — 0.83 dB for the DPAI-yes/1-dot, from 5.5 — 9.0 dB for the DPAI-no/2-dot, and from -2.67 — 1.17 for the DPAI-no/1-dot condition.

In accordance with the American Academy of Audiology (2008b) recommendations for the electroacoustic verification of FM, a mean three-frequency (750, 1000, 2000 Hz) average FM offset value was calculated for each of the Eleva, Savia, and Una hearing aids in each DPAI/dot condition. These data are shown in Figure 3. As may be seen by the figure, for each aid the mean three-frequency average FM offset value was within the recommended +/- 2 dB transparency tolerances (represented by the dashed lines) in the DPAI-yes/2-dot, DPAI-yes/1-dot, and DPAI-no/1-dot conditions. In contrast, FM offset exceeded the +2 dB tolerance threshold in the DPAI-no/2-dot condition for each of these instruments (i.e., Eleva = 5.89 dB, Savia = 6.94 dB, Una = 6.22 dB).

Table 3 shows mean FM offset by frequency, 250—4000 Hz, as a function of MicroMLxS setting for the Conversa NT, Element 4, and Element 8 instruments. As may be seen by these data, mean FM offset ranged from -1.83 — 1.17 dB, from 0.33 — 9.0 dB, and from 0 — 9.17 dB for the Conversa NT, Element 4, and Element 8 instruments, respectively. Collapsing across aids, mean FM offset values ranged from -0.83 — 2.0 dB for the DPAI-yes/2-dot condition, from -1.17 — 1.67 dB for the DPAI-yes/1-dot condition, from -1.83 — 9.17 dB for the DPAI-no/2-dot condition, and from -1.17 — 1.83 for the DPAI-no/1-dot condition.

Figure 4 shows mean three-frequency average FM offset as a function of DPAI/dot condition for the Conversa NT, Element 4,

Table 2. Mean FM offset, in dB, as a function of MicroMLxS DPAI/dot setting for the Eleva, Savia and Una hearing instruments, 250—4000 Hz (standard deviations in parentheses).

Hearing Instrument	DPAI	dot	250	500	750	1K	1.5K	2K	3K	4K	Range
Eleva	yes	2	-3.33 (0.82)	-1.33 (0.52)	-1.0 (0)	-1.0 (0)	-0.83 (0.41)	-.033 (0.52)	0.67 (0.52)	-0.17 (0.41)	-3.33 — 0.67
		1	-2.83 (0.41)	-1.0 (0)	-1.0 (0)	-1.0 (0)	-0.83 (0.41)	-0.17 (0.41)	0.17 (0.41)	0.67 (0.52)	-2.33 — 0.67
	no	2	5.83 (0.41)	6.0 (0.89)	6.0 (0)	6.0 (0)	6.0 (0.63)	5.67 (0.52)	6.0 (0.63)	6.5 (0.55)	5.67 — 6.5
		1	-2.67 (1.63)	-1.0 (0)	-1.17 (0.41)	-0.17 (0.41)	-0.5 (0.55)	0 (0.63)	0.83 (0.41)	0.67 (0.52)	-2.67 — 0.83
Savia	yes	2	-1.83 (0.75)	-0.33 (0.52)	0 (0)	0 (0)	0 (0)	0.33 (0.52)	0.33 (0.52)	0.83 (0.41)	-1.83 — 0.83
		1	-1.5 (0.55)	-0.67 (0.52)	0 (0)	0 (0)	0 (0)	0.33 (0.52)	0.17 (0.41)	0.83 (0.41)	-1.5 — 0.83
	no	2	6.67 (0.52)	7.5 (0.84)	7.0 (0)	7.0 (0)	6.83 (0.41)	6.83 (0.41)	7.83 (0.75)	9.0 (0.63)	6.67 — 9.0
		1	-2.17 (0.75)	0 (0)	-0.17 (0.41)	0 (0)	0 (0)	0.83 (0.41)	1.17 (0.75)	1.0 (0)	-2.17 — 1.17
Una	yes	2	-2.33 (0.82)	-0.67 (0.52)	-1.0 (0)	0 (0)	0 (0)	0 (0)	0.5 (0.84)	0.83 (0.75)	-2.33 — 0.83
		1	-2.33 (0.52)	-1.17 (0.41)	-1.0 (0)	0 (0)	0 (0)	0 (0)	0.5 (0.55)	0.83 (0.75)	-2.33 — 0.83
	no	2	5.5 (0.55)	6.67 (0.82)	6.0 (0)	6.83 (0.41)	5.83 (0.41)	5.83 (0.41)	6.0 (0.63)	5.83 (0.41)	5.5 — 6.83
		1	-2.33 (0.82)	-1.5 (0.55)	-1.0 (0)	0 (0)	-0.67 (0.52)	-0.17 (0.41)	0.17 (0.75)	0.5 (0.55)	-2.33 — 0.5

and Element 8 hearing aids. As may be seen by Figure 4, mean three-frequency average FM offset was within +/- 2 dB for each hearing instrument in the DPAI-yes/2-dot, DPAI-yes/1-dot, and DPAI-no/1-dot conditions. As may also be seen by the figure, mean three-frequency average FM offset exceeded the +2 dB tolerance threshold for the Element 4 and Element 8 instruments in the DPAI-no/2-dot condition (i.e., Element 4 = 8.11 dB, Element 8 = 7.33 dB), but was within +/- 2 dB for the Conversa NT.

Muted-FM Offset

Tables 4 and 5 display mean muted-FM offset, 250—4000 Hz, as a function of MicroMLxS setting for the Eleva, Savia, and Una (Table 4) and the Conversa NT, Element 4, and Element 8 instruments (Table 5). As may be seen in the tables, mean muted-FM offset ranged from -1.0 — 0 dB across all instruments in all DPAI/dot conditions.

Discussion

The data of the present study indicated that for the Eleva, Savia, Una, Element 4, and Element 8 instruments, mean three-frequency average FM offset when coupled to a MicroMLxS/Campus Sx FM system was within the American

Figure 3. Mean three-frequency (750, 1000, 2000 Hz) average FM offset (in dB) as a function of MicroMLxS setting for the Eleva, Savia and Una hearing instruments. Dashed lines represent +/-2 dB transparency tolerances (AAA, 2008b). Vertical bars indicate +/- 1 standard deviation.

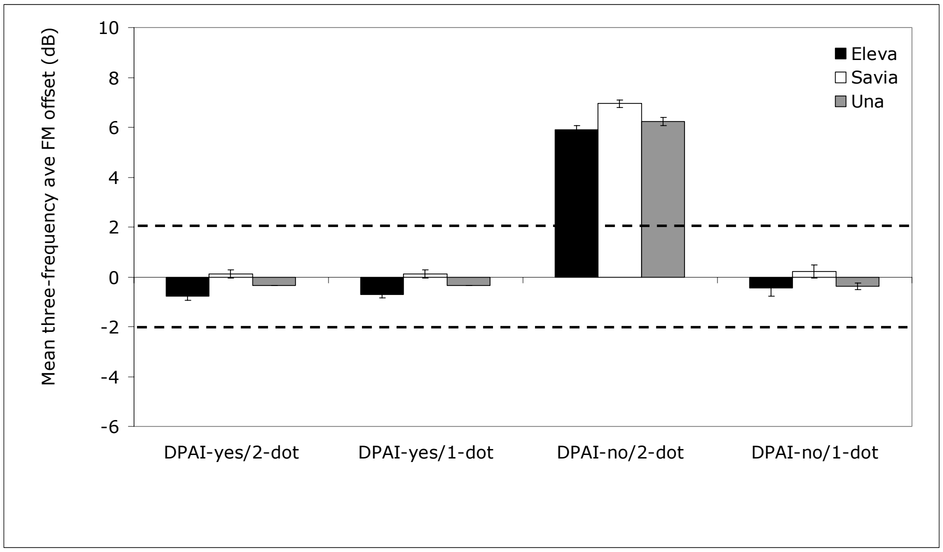


Table 3. Mean FM offset, in dB, as a function of MicroMLxS DPAI/dot setting for the Conversa NT, Element 4 and Element 8 hearing instruments, 250—4000 Hz (standard deviations in parentheses).

Hearing Instrument	DPAI	dot	250	500	750	1K	1.5K	2K	3K	4K	Range
Conversa NT	yes	2	-0.83 (0.75)	0.33 (0.52)	-0.33 (0.82)	0 (0)	-0.17 (0.98)	0 (0.63)	-0.33 (0.52)	-0.83 (0.41)	-0.83 — 0.33
		1	-0.33 (0.52)	0 (0)	-0.5 (0.55)	0.17 (0.75)	-0.5 (0.55)	-0.17 (0.41)	-0.17 (0.41)	-1.17 (0.41)	-1.17 — 0.17
	no	2	0.33 (0.82)	1.17 (0.75)	0 (0)	0.5 (0.84)	0.5 (0.55)	-0.17 (0.98)	-0.33 (0.52)	-1.83 (0.75)	-1.83 — 1.17
		1	-0.17 (0.75)	0.33 (0.52)	-0.83 (0.41)	0.17 (0.41)	-0.33 (0.52)	-0.33 (0.52)	-0.33 (0.52)	-1.17 (0.41)	-1.17 — 0.33
Element 4	yes	2	1.0 (0.63)	1.5 (0.55)	1.0 (0)	1.67 (0.52)	1.17 (0.41)	1.5 (0.55)	1.33 (0.52)	2.0 (0)	1.0 — 2.0
		1	1.17 (0.41)	1.83 (0.41)	1.0 (0)	1.83 (0.41)	1.5 (0.55)	1.5 (0.55)	1.67 (0.52)	1.83 (0.41)	1.0 — 1.83
	no	2	8.33 (0.52)	9.0 (0.63)	8.17 (0.41)	8.33 (0.52)	7.33 (0.52)	7.83 (0.41)	7.33 (0.52)	7.33 (0.52)	7.33 — 9.0
		1	0.33 (0.52)	1.5 (0.55)	1.0 (0)	1.83 (0.41)	1.0 (0)	1.33 (0.52)	1.17 (0.75)	1.83 (0.41)	0.33 — 1.83
Element 8	yes	2	2.0 (0)	0.5 (0.55)	0.33 (0.52)	0 (0)	0 (0)	1.0 (0)	0 (0)	1.0 (0)	0 — 2.0
		1	1.67 (0.52)	1.17 (0.41)	0 (0)	0.17 (0.41)	0 (0)	1.0 (0)	0.17 (0.41)	0.83 (0.41)	0 — 1.67
	no	2	9.17 (0.41)	8.17 (0.75)	7.67 (0.52)	7.33 (0.52)	6.0 (0)	7.0 (0)	6.0 (0)	6.67 (0.52)	6.0 — 9.17
		1	1.67 (0.82)	0.83 (0.41)	0.5 (0.55)	0.17 (0.41)	0 (0)	1.0 (0)	0.17 (0.41)	0.67 (0.52)	0 — 1.67

Academy of Audiology (2008b) +/-2 dB FM transparency tolerances, and thus FM transparency was achieved for the DPAI-yes/2-dot, DPAI-yes/1-dot, and DPAI-no/1-dot conditions. These data suggest that for these instruments in these settings, the FM receiver would deliver the appropriate FM signal level to the HA during regular listening (i.e., 75 dB SPL equivalent-input) and thus the expected FM advantage (e.g., +10 dB) would be provided to the listener. For these same five instruments in the DPAI-no/2-dot condition, the data of the present study indicated that mean three-frequency average FM offset exceeded the +2 dB tolerance threshold by as much as 8 dB (i.e., FM transparency was not achieved). These findings suggest that for these instruments in this condition, the FM system would produce an above-target FM signal during regular listening (e.g., 83 dB SPL equivalent-input, given +8 dB of FM offset), and

Figure 4. Mean three-frequency (750, 1000, 2000 Hz) average FM offset as a function of MicroMLxS setting for the Conversa NT, Element 4, and Element 8 hearing instruments. Dashed lines represent +/-2 dB transparency tolerances (AAA, 2008b). Vertical bars indicate +/- 1 standard deviation.

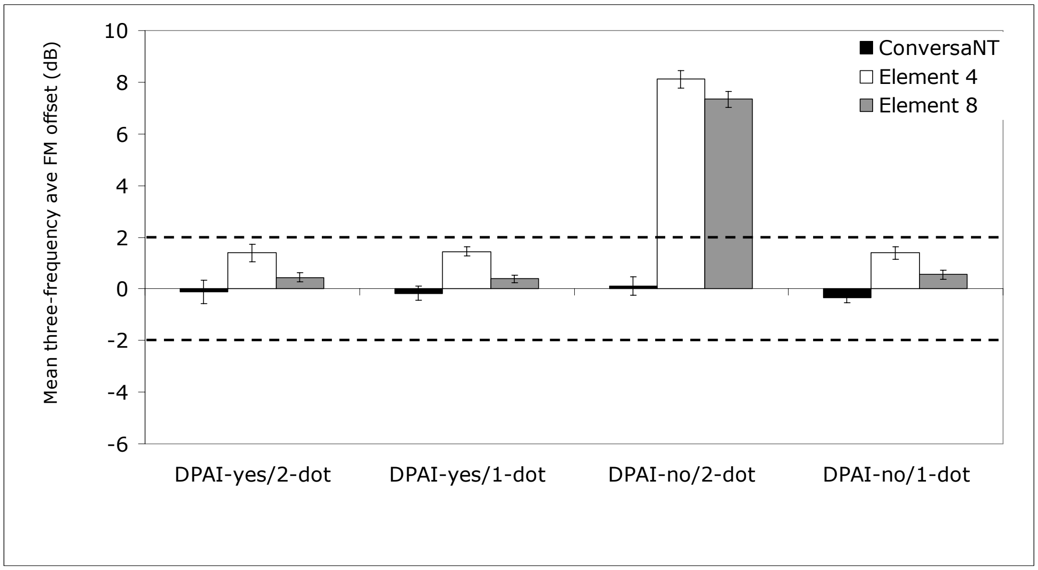


Table 4. Mean muted-FM offset, in dB, as a function of MicroMLxS DPAI/dot setting for the Eleva, Savia and Una hearing instruments, 250—4000 Hz (standard deviations in parentheses).

Hearing Instrument	DPAI	dot	250	500	750	1K	1.5K	2K	3K	4K	Range
Eleva	yes	2	-0.5 (0.55)	-0.83 (0.41)	-0.67 (0.52)	-0.33 (0.52)	0 (0)	-0.67 (0.52)	-0.67 (0.52)	0 (0)	-0.33 — 0
		1	-1.0 (0.63)	-0.33 (0.52)	-0.17 (0.41)	0 (0)	0 (0)	-0.83 (0.41)	-0.17 (0.41)	-0.67 (0.52)	-1.0 — 0
	no	2	-0.67 (0.82)	-0.5 (0.55)	-0.33 (0.52)	-0.17 (0.41)	-0.67 (0.52)	-0.67 (0.52)	-0.67 (0.52)	-1.0 (0)	-1.0 — -0.17
		1	-0.5 (0.55)	-0.5 (0.55)	-0.5 (0.55)	-0.83 (0.41)	-0.5 (0.55)	-0.83 (0.41)	-0.33 (0.52)	-0.83 (0.41)	-0.83 — -0.33
Savia	yes	2	-0.33 (0.52)	-0.17 (0.41)	0 (0)	-0.5 (0.55)	-0.33 (0.52)	-0.83 (0.41)	-0.33 (0.52)	-0.67 (0.52)	-0.83 — 0
		1	-0.5 (0.55)	0 (0)	0 (0)	-0.5 (0.55)	-0.17 (0.41)	-0.33 (0.52)	-0.33 (0.52)	-0.83 (0.41)	-0.83 — 0
	no	2	-0.5 (0.55)	-0.33 (0.52)	0 (0)	-0.67 (0.52)	-0.5 (0.55)	-0.83 (0.41)	-0.17 (0.41)	-0.5 (0.55)	-0.83 — 0
		1	-0.17 (0.41)	0 (0)	0 (0)	-0.5 (0.55)	0 (0)	-0.67 (0.52)	-0.5 (0.55)	-0.33 (0.52)	-0.67 — 0
Una	yes	2	-1.0 (0.63)	-0.83 (0.75)	0 (0)	-0.67 (0.52)	0 (0)	0 (0)	-0.17 (0.41)	-0.17 (0.41)	-1.0 — 0
		1	-0.5 (0.84)	-0.5 (0.55)	0 (0)	-0.5 (0.55)	0 (0)	0 (0)	0 (0)	-0.5 (0.55)	-0.5 — 0
	no	2	-0.5 (0.55)	-1.0 (0)	0 (0)	-0.67 (0.52)	0 (0)	0 (0)	-0.17 (0.41)	-0.17 (0.41)	-1.0 — 0
		1	-0.5 (0.55)	-0.5 (0.55)	0 (0)	-0.83 (0.41)	0 (0)	0 (0)	-0.17 (0.41)	-0.5 (0.55)	-0.83 — 0

thus the expected FM advantage would not be achieved. Finally, for these five instruments, the present study's findings indicated that mean three-frequency average muted-FM offset was within transparency tolerances for each DPAI/dot setting (i.e, muted-FM transparency was achieved for all instruments in all conditions). These data suggest that for these instruments, hearing aid performance during regular listening would be unaffected by FM microphone muting, regardless of FM receiver setting.

The present study's FM and muted-FM offset findings for the Eleva, Savia, Una, Element 4, and Element 8 instruments are consistent with descriptions of FM system performance (Platz, 2004, 2006). For FM systems generally, +/- 1 dB of FM offset may be expected, due to variations in FM transmitter and receiver performance (Platz, 2004). When coupled to a DPAI-HA, additional sources of FM offset may include the hearing instrument's DAI-signal pre-amplifier, HA coupling, and the level of the FM signal delivered to the hearing instrument by the FM receiver (Platz, 2004). Importantly, FM signal level may increase by 10-15 dB if the signal is changed from low to high impedance (R. Platz, personal communication, September 27, 2007). For the present study, FM offset was low for the Eleva, Savia, Una, Element 4, and Element 8 in the low-impedance FM conditions of DPAI-yes/2-dot, DPAI-yes/1-dot, and DPAI-no/1-dot, and FM offset was high for the high-impedance DPAI-no/2-dot condition. Similarly, muted-FM offset was low for each aid in each condition, when an FM signal was not delivered to the HA and thus sources of offset were (presumably) limited to coupling effects. The data suggest that for these instruments and FM receiver settings, muting the FM microphone will not adversely affect student listening via the hearing aid's environmental microphone. These findings further suggest that for these HA and FM instruments, the DPAI-yes/2-dot, DPAI-yes/1-dot, and DPAI-no/1-dot settings are equally appropriate for HA+FM classroom listening, while the DPAI-no/2-dot setting should not be used.

These data have implications for the management of MicroMLxS FM receivers used with DPAI hearing instruments in the schools. Specifically, although a manufacturer may recommend one MicroMLxS receiver setting when coupled to a DPAI hearing instrument (e.g., DPAI-no/1-dot for a DPAI-HA, see: www.phonak.com/professional/eschooldesk), the data from the present study suggest that educational audiologists may choose between the DPAI-yes/2-dot, DPAI-yes/1-dot, and

Table 5. Mean muted-FM offset, in dB, as a function of MicroMLxS DPAI/dot setting for the Conversa NT, Element 4 and Element 8 hearing instruments, 250—4000 Hz (standard deviations in parentheses).

Hearing Instrument	DPAI	dot	250	500	750	1K	1.5K	2K	3K	4K	Range
Conversa NT	yes	2	-0.17 (0.75)	-0.5 (0.55)	-0.33 (0.52)	-0.5 (0.55)	-0.83 (0.75)	-0.5 (0.84)	-0.5 (0.55)	-1.0 (0.89)	-1.0 — -0.17
		1	0 (0)	-0.67 (0.52)	0 (0)	-0.67 (0.52)	-0.5 (0.84)	-0.83 (0.41)	-0.5 (0.84)	-0.5 (0.55)	-0.83 — 0
	no	2	-0.5 (0.55)	-0.5 (0.55)	-0.17 (0.41)	-0.67 (0.52)	-0.67 (0.52)	-0.33 (0.52)	-0.33 (0.52)	-0.5 (0.55)	-0.67 — -0.17
		1	-0.5 (0.84)	-0.33 (0.52)	-0.17 (0.41)	-0.67 (0.52)	-0.5 (0.84)	-0.67 (0.52)	-0.5 (0.55)	-0.67 (0.52)	-0.67 — -0.17
Element 4	yes	2	-0.5 (0.55)	0 (0)	0 (0)	-0.17 (0.41)	-0.17 (0.41)	-0.67 (0.52)	-0.33 (0.52)	-1.0 (0)	-1.0 — 0
		1	-0.5 (0.55)	-0.83 (0.75)	0 (0)	-0.17 (0.41)	-0.5 (0.55)	-0.67 (0.52)	-0.67 (0.52)	-0.83 (0.41)	-0.83 — 0
	no	2	-0.5 (0.55)	-0.5 (0.55)	0 (0)	-0.17 (0.41)	0 (0)	-0.5 (0.55)	-0.33 (0.52)	-0.17 (0.41)	-0.5 — 0
		1	0 (0)	-0.33 (0.52)	0 (0)	-0.33 (0.52)	0 (0)	-0.5 (0.55)	-0.17 (0.75)	-0.83 (0.41)	-0.83 — 0
Element 8	yes	2	-1.0 (0)	-0.5 (0.55)	-0.33 (0.52)	0 (0)	0 (0)	-1.0 (0)	0 (0)	-0.83 (0.41)	-1.0 — 0
		1	-0.67 (0.82)	-1.0 (0)	0 (0)	-0.17 (0.41)	0 (0)	-1.0 (0)	0 (0)	-0.83 (0.41)	-1.0 — 0
	no	2	-0.67 (0.52)	-0.83 (0.41)	-0.67 (0.52)	-0.33 (0.52)	0 (0)	-0.33 (0.52)	0 (0)	-0.5 (0.55)	-0.83 — 0
		1	-1.0 (0)	-0.67 (0.52)	-0.5 (0.55)	0 (0)	0 (0)	0 (0)	0 (0)	-0.33 (0.52)	-1.0 — 0

DPAI-no/1-dot settings as equally appropriate alternatives. This flexibility may be helpful in cases where a MicroMLxS is to be used with a DPAI-HA and there are concerns that the FM receiver's external switch may be changed from the one- to the two-dot position. For example, in classrooms where teachers work with multiple FM receivers, some of which are to be used with DPAI-HAs and some with non-DPAI HAs, setting those receivers that are paired with DPAI-HAs to "Hearing Instrument with DPAI = yes" will simplify the management of these systems by allowing them all to be used in the same (two-dot) switch position.

Resetting MicroMLxS receivers from the factory default to "Hearing Instrument with DPAI = yes," however, requires careful FM and HA management to ensure that such FM receivers are only used with DPAI-yes hearing instruments. Although not examined in this study, the present findings suggest that coupling a MicroMLxS receiver set to "Hearing Instrument with DPAI = yes" to a non-DPAI hearing aid will result in an undesirable muting of the HA microphone. Thus, it should be made clear to students and school personnel that FM receivers are fit to specific hearing instruments and must not be exchanged between students or between one student's current and older/back-up hearing aids (as these other instruments may be non-DPAI). Similarly, should MicroMLxS FM receivers be used with DPAI-yes hearing aids while set to "Hearing Instrument with DPAI = no," students and teachers should understand that the external switch must remain in the one-dot position for the system to function appropriately (that is, at the FM advantage determined by the educational audiologist). If this switch setting is changed to the two-dot position, and thus the intensity of the FM signal is increased, students may complain that the teacher's voice is too loud, or that environmental inputs or the voices of their peers are not clear.

Unlike the pattern of results for the Eleva, Savia, Una, Element 4, and Element 8 instruments, for the Conversa NT the data of the present study indicated that mean three-frequency average FM and muted-FM offset were within +/- 2 dB transparency tolerances for all DPAI/dot conditions. These findings are not consistent with manufacturer's descriptions of FM system performance in that high FM signal levels were not noted for the DPAI-no/2-dot condition, and FM transparency was achieved for each DPAI/dot setting. One possible explanation for this FM offset finding is that unlike the other aids studied, FM signals for the Conversa NT are routed through the instrument's telecoil (personal communication, J. Dossin, October, 2008). If this pathway is insensitive to variations in FM signal impedance, then high- versus low-impedance FM signals may not be associated with differences in FM signal level and thus offset. Notably, although FM offset was within transparency tolerances for this aid in all DPAI/dot conditions, listening checks revealed poor, noisy sound quality for the FM. These data highlight the importance of verifying the performance of each HA+FM system in each DPAI/dot setting intended for classroom use, both electroacoustically and via a listening check.

The findings of the present study should be interpreted with caution, given the small number of instruments and manufacturers examined. It is important to note that while the Eleva, Savia, Una, Element 4, and Element 8 instruments of the present study performed within tolerances (AAA, 2008b), within-model device variability in microphone impedance may be expected to occur as part of the manufacturing process. Therefore, verification of system performance is always recommended (AAA, 2008a, 2008b). Further research including additional hearing instruments, more than one example of each aid, and other FM receivers may broaden our understanding of the performance of these systems with DPAI hearing aids. In addition, as noted above, the present study did not examine the effect of MicroMLxS DPAI/dot setting on FM offset and muted-FM offset for non-DPAI hearing instruments. Although an older technology, non-DPAI instruments may be used for many years as loaner and back-up hearing aids. Thus, data confirming the performance of the MicroMLxS with non-DPAI instruments will be important for the effective use of such HA+FM systems in the classroom.

In summary, the data of the present study suggest that for each of the six hearing aids studied, the DPAI-yes/2-dot, DPAI-yes/1-dot, and DPAI-no/1-dot MicroMLxS receiver settings demonstrate FM transparency and muted-FM transparency and thus are equally appropriate for HA+FM classroom listening when used with an active or a muted FM (lapel) microphone. The data also suggest that for the Eleva, Savia, Una, Element 4, and Element 8 instruments, the DPAI-no/2-dot MicroMLxS receiver setting does not demonstrate FM transparency, and thus would not be appropriate for HA+FM listening. However, the findings of the present study also indicated that although FM transparency and muted-FM transparency were achieved for the Conversa NT instrument in all DPAI/dot conditions, the sound quality of the FM signals processed through the instrument was subjectively poor. Overall, these findings highlight the importance of verifying HA+FM system performance (both electroacoustically and by a listening check) and suggest that audiologists have choices in the MicroMLxS settings that may be appropriately used with DPAI hearing instruments for classroom listening.

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References

American Academy of Audiology (2008a). *American Academy of Audiology clinical practice guidelines: Remote microphone hearing assistance technologies for children and youth birth-21 years*. Retrieved from http://www.audiology.org/resources/documentlibrary/Documents/HATGuideline042208.pdf.

American Academy of Audiology (2008b). *American Academy of Audiology clinical practice guidelines: Remote microphone hearing assistance technologies for children and youth birth - 21 years, Supplement A: Fitting and verification procedures for ear-level FM*. Retrieved from http://www.audiology.org/resources/documentlibrary/Documents/HATSup042208.pdf.

American National Standards Institute (2003). *American national standard for the specification of hearing aid characteristics (ANSI S3.22-2003)*. New York: Author.

American Speech-Language-Hearing Association (2002). Guidelines for fitting and monitoring systems. *ASHA Desk Reference, 2*, 151-171.

Finitzo-Hieber, T. & Tillman, T. (1978). Room acoustics effects on monosyllabic word discrimination ability for normal and hearing impaired children. *Journal of Speech and Hearing Research, 21*, 440-458.

FM Successware v3.5 [Computer software]. Phonak Hearing Systems.

Hawkins, D. B. (1984). Comparisons of speech recognition in noise by mildly-to-moderately hearing-impaired children using hearing aids and FM systems. *Journal of Speech and Hearing Disorders, 49,* 409-418.

Lewis, M. S., Crandell, C. C., Valente, M. & Horn, J. E. (2004). Speech perception in noise: Directional microphones versus frequency modulation (FM) systems. *Journal of the American Academy of Audiology, 15,* 426-439.

iPFG Successware v2.1 [Computer software]. Phonak Hearing Systems.

Pittman, A. L., Lewis, D. E., Hoover, B. M. & Stelmachowicz, P. G. (1999). Recognition performance for four combinations of FM system and hearing aid microphone signals in adverse listening conditions. *Ear and Hearing, 20,* 279-289.

Platz, R. (2004). SNR Advantage, FM Advantage and FM Fitting. In D. Fabry (Ed.), *ACCESS: Achieving Clear Communication Employing Sound Solutions 2003: Proceedings from the first international FM conference* (pp. 147-154). Warrenville, IL: Phonak.

Platz, R. (2006, April). *New insights and developments in verification of FM systems.* Paper presented at the Phonak Communications AG Meeting, Minneapolis, MN.

Schafer, E. C., Thibodeau, L. M., Whalen, H. S. & Overson, G. J. (2007). Electroacoustic evaluation of frequency-modulated receivers interfaced with personal hearing aids. *Language Speech and Hearing Services in the Schools*, *38*, 315-326.

U:fit v1.4.2 [Computer software]. Unitron Hearing Ltd.

Unifit v5.5 [Computer software]. Unitron Hearing Ltd.