`icaOcularCorrection`: Independent Components Analysis Based Artifact Correction

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Abstract

The present vignette shows how to remove blink and eye-movement artifacts using the `icaOcularCorrection` version 3.010 or greater. Worked examples are provide as well as the data to run them.

Keywords: ocular artifact removal; EEG; ERP; electro-encephalogram; event-related potentials; R.

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1 Removing Ocular Artifacts in EEG Recordings

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1.1 Introduction to Independent Components Analysis (ICA) and to ICA-based Denoising

The first two subsections of the *ICA Ocular Correction* section are taken verbatim from Arnaud Delorme, `http://sccn.ucsd.edu/ arno/indexica.html`. The `MATLAB` code was translated to `R`.

1.1.1 Introduction ICA is a quite powerful technique and is able (in principle) to separate independent sources linearly mixed in several sensors. For instance, when recording electroencephalograms (EEG) on the scalp, ICA can separate out artifacts embedded in the data (since they are usually independent of each other).

This page intends to explain ICA to researchers that want to understand it but only have a weak background both in matrix computation and information theory. My [Arnaud's] explanations will be as intuitive as possible and based on practical examples from Matlab. [translated to `R`].

1.1.2 What is ICA ICA is a technique to separate linearly mixed sources. For instance, let's try to mix and then separate two sources. Let's define the time courses of 2 independent sources A(top) and B(bottom)

```
> A <- sin(seq(0,50,length.out=1000))    # A
> B <- sin(seq(0,37,length.out=1000)+5) # B
> par(mfrow=c(3,2))
> plot(A,type="l")
> plot(B,type="l")
```

We then mix linearly these two sources. The top curve is equal to A minus twice B and the bottom the linear combination is 1.73*A +3.41*B.

```
> M1 <- A - 2*B # mixing 1
> M2 <- 1.73*A+3.41*B # mixing 2
```

```
> plot(M1,type="l")
> plot(M2,type="l")
```

We then input these two signals into the ICA algorithm (in this case, fastICA) which is able to uncover the original activation of A and B.

```
> library(fastICA)
> mat<-cbind(M1,M2)
> m <- fastICA(mat,n.comp=2) # compute and plot unminxing using fastICA
> names(m)
> # [1] "X" "K" "W" "A" "S"
> plot(m$S[,1],type="l")
> plot(m$S[,2],type="l")
```

Note that the algorithm cannot recover the exact amplitude of the source activities. I advise you to try this with different degree of noise and see that it's quite robust. Note also that, in theory, ICA can only extract sources that are combined linearly.

1.1.3 The `icaOcularCorrection` Package

```
> # load data
> load("data/eeg/rda/omega-11_CR_data_rshp_128Hz_rrf_hp_bas.rda")
> # make it shorter to speed up the example,
> # there are full bloum examples below
> dat<-dat[dat$Trial>=1&dat$Trial<=10,]
> library(icaOcularCorrection)
> electrodes<-c(des("biosemi.32")$electrodes,"TE","BE","LC","RC")
> datc<-icac(dat,channel=electrodes,noise.sig=c("TE","BE","LC","RC"),
+         verbosity=1)
```

```
fastICA ...
correcting based on noise signal TE ...

correcting based on noise signal BE ...

correcting based on noise signal LC ...

correcting based on noise signal RC ...

re-mixing ICs ...
```

```
> names(datc)
```

```
 [1] "data"            "channel"         "noise.sig"       "threshold"
 [5] "n.comp"          "X"               "K"               "W"
 [9] "A"               "S"               "S0"              "col.means"
[13] "correlations"    "correction.info" "proctime"
```

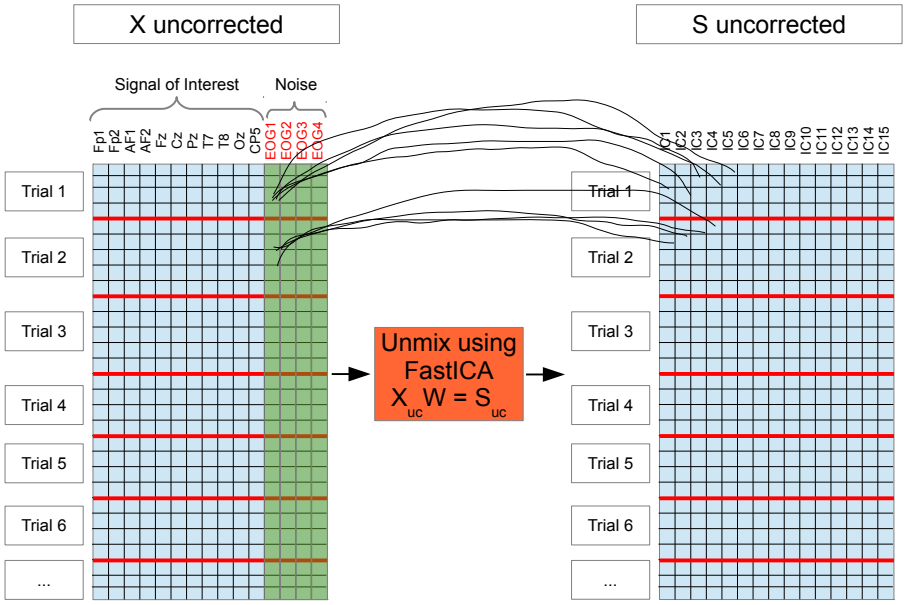

Figure 1. Unmixing the EEG signals via fastICA and measuring the correlation between each "noise signal" and each independent component (IC) for each trial. Columns in light blue correspond to the EEG signal of interest. The ones in green correspond to simultaneously recorded noise signals (in this case EOGs).

```
> head(datc$S)
```

```
           V1         V2         V3         V4         V5         V6         V7
1  0.27976533 -1.1770321  1.2528515 0.04967419  0.9777238 -0.2239842  0.5928421
2  0.60633999  0.1044205  1.2426734 0.56898181  0.9044877  0.3889460 -0.0161030
3  0.77584033 -0.6020046  1.1418707 1.85610147 -0.1963406  0.6781889  0.5048715
4  0.76239078  0.9452186  1.0520340 0.26757021  0.6130904  0.4066879  0.4212766
5 -0.09281334 -0.0896114 -0.5901471 0.78552774 -1.4616273 -0.5322155  0.9319009
6  0.45858786 -0.4937157  1.2202356 0.75184090  0.4656564 -1.0219249 -0.4484277
           V8          V9         V10        V11        V12        V13
1 -0.01992295 -0.57973382 -0.01088733  0.6051932  0.3932038  0.4298564
2 -0.48835643 -0.39136856  0.06391946  0.4280178  0.3915926 -0.1508506
3 -0.06599447 -0.44508350 -0.31777293  1.7603718  0.4402470 -0.5195898
4  2.46933475 -0.96866171 -2.49786922 -0.5666931 -0.8306729  0.3660232
5 -1.44095125 -0.04424895  0.10282663  3.1659694 -0.7330625  0.1774846
6 -1.72742263 -0.69871283  0.41851718  1.5731039 -0.3302086 -1.1642544
          V14        V15 V16         V17         V18        V19         V20
```

```
1 -0.34519663 -0.5365575   0  0.28373730 -3.11962539  0.1824807 -0.50587096
2  0.12678542 -1.5209705   0 -0.23557483 -3.11356034  0.3237094 -0.26944041
3 -0.97770710  0.2120481   0  0.04759532 -2.61233218 -0.2637068 -0.39071327
4  1.48191526  1.1980002   0 -0.48571910 -0.87944928 -0.4515405 -1.48866123
5 -0.37880297  0.1289365   0 -0.39010533  0.04408921  0.7100880 -0.00432495
6 -0.07104293 -1.3949316   0  0.35967585  0.19978907  0.4135114 -0.69600749
         V21        V22          V23 V24        V25         V26         V27
1 -0.6561261  0.6133457 -0.004586097   0  1.3558142  0.06406141 -0.49733905
2 -0.9022963  0.5418951  0.083340577   0  0.5081054 -0.90760820 -0.07350185
3 -0.2223738  0.3953863 -0.297656289   0 -0.1633848 -1.04985858 -0.27933389
4 -0.5632412  0.9283560  0.887431744   0  0.9755539  1.67174368  0.33969106
5 -0.1364434 -0.4709284 -0.129288783   0 -0.3024637 -0.85654448 -2.20808289
6 -0.1916251 -0.3103489 -0.582032110   0 -0.4126146  0.95241534 -1.40143668
         V28         V29         V30         V31        V32        V33
1 -0.9060769 -0.05313280 -0.05352837 -0.08818155 -0.9689582 -0.6621888
2 -0.3202383  0.97414916  0.31719884 -2.14689039  0.3073683 -0.4645223
3 -0.7615690  0.23870613  0.92953821 -0.99500263 -2.1893266 -0.9501225
4 -1.6329495 -0.07263479 -0.13978728 -1.56419652  0.5081920 -0.2263278
5 -0.3724490 -1.28227385  0.08395296  0.29242778 -0.2574310 -0.0842715
6 -0.4943738 -0.50059274 -0.04752102  0.63202116 -1.4662939  0.9933730
         V34        V35        V36
1  0.3242928 -0.2475188 -0.8169802
2  0.3641064  0.4605588  0.1555480
3  1.1202364 -1.3119835  1.2370314
4  1.0115462 -1.0247071  2.0036169
5 -1.4205195  0.3222129 -2.4877727
6  0.4415875 -1.4511005 -0.4587801
```

```
> head(datc$correlations)
```

```
[1] "noise signal = TE; trial = 1; IC = 1; cor = 0.0710758452675917"
[2] "noise signal = TE; trial = 1; IC = 2; cor = 0.105662505238776"
[3] "noise signal = TE; trial = 1; IC = 3; cor = -0.080138332657599"
[4] "noise signal = TE; trial = 1; IC = 4; cor = -0.0291724129567605"
[5] "noise signal = TE; trial = 1; IC = 5; cor = -0.0566108193963089"
[6] "noise signal = TE; trial = 1; IC = 6; cor = -0.0997780734494712"
```

```
> head(smry<-summary(datc,print=FALSE))
```

```
  IC NumTrials  MeanCorr
1 24        18 0.5919328
2 11        15 0.5012348
3 19         7 0.6097740
4 30         7 0.4979512
5 33         6 0.4358460
6 28         5 0.6179063
```

Figure 2. For each trial, zero-out independent components (ICs) that correlate at or above threshold with the noise signals. Also, by looking at the correction summary and a plots of the scalp distribution of independent components, determine which IC to completely zero-out, if any. Portions of columns in red correspond to sections of the source matrix that were zeroed out. Details are as in Figure 1.

```
> summary(datc,ic=smry$IC[1])
```

```
SUMMARY FOR IC = 24:
  IC NoiseSignal NumTrials  MeanCorr
1 24          TE         5 0.6242053
2 24          BE         7 0.5543268
3 24          LC         5 0.5750376
4 24          RC         1 0.7782883
----------
NOTE: More info available in ICAC_OBJECT$correction.info
```

1.2 Perform ICA Correction

```
> ##########################################################
> #                Perform ICA Correction                  #
```

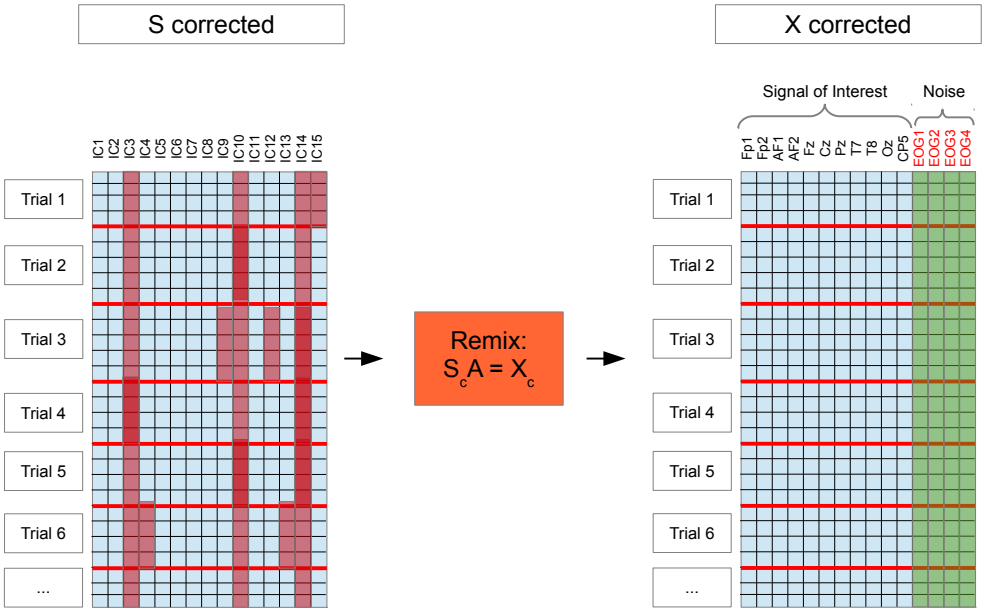

Figure 3. Once the ICs correlating at or above threshold with noise signals were (partially) zeroed-out, re-mix the corrected source matrix. Details are as in Figure 1.

```
> ##########################################################
> load("data/eeg/rda/omega-11_CR_data_rshp_128Hz_rrf_hp_bas.rda")
> library(icaOcularCorrection)
> electrodes<-c(des("biosemi.32")$electrodes,"TE","BE","LC","RC")
> datc<-icac(dat,channel=electrodes,noise.sig=c("TE","BE","LC","RC"))
> #                 user       system  elapsed
> # start time 0.1185333 0.002533333 1.046117
> # end time   9.0464167 0.033066667 9.940250
> # run time   8.9278833 0.030533333 8.894133
> #
> ### took about 9 minutes to run
> #
> dir.create("data/eeg/corrected/")
> save(datc,file="data/eeg/corrected/omega-11_CR_data_rshp_128Hz_
+         rrf_hp_bas_icac.tmp.rda")
```

1.3 Look at Correction Summary

```
> ########################################################
> #              Look at Correction Summary              #
> ########################################################
> smry<-summary(datc,print=FALSE)
> save(smry,file="data/eeg/corrected/omega-11_CR_icac.smry.rda")
> #
> pdf(file="figs/icac_smry.pdf")
> plot_smry(smry,lwd=2,col=1:datc$n.comp)
> dev.off()
> head(smry)
>   IC NumTrials  MeanCorr
> 1 25      1354 0.7862235
> 2 24       974 0.5994915
> 3  6       939 0.6309125
> 4 36       466 0.5417662
> 5 11       376 0.5094461
> 6  8       375 0.5316904
>
> ### ICs 25, 24, and 6 appear to be the main contributors
> ### of blinks and eye-movements (+ some amount of other types
> ### of noise).
```

1.4 Look at IC Scalp Topographies

```
> ########################################################
> #             Look at IC Scalp Topographies            #
> ########################################################
> dir.create("figs/omega-11_ICs",recursive=TRUE)
> pb<-txtProgressBar(min=1,max=nrow(smry),style=3)
> for(ii in 1:nrow(smry)){
+         setTxtProgressBar(pb,ii)
+         png(filename=paste("figs/omega-11_ICs/rank",ii,
+                 "_IC",smry[ii,"IC"],".png",sep=""))
+         pi<-topo_ic(datc,ic=smry[ii,"IC"],coords="biosemi.32")
+         dev.off()
+ }
> close(pb)
```

In order to view the IC topographic maps, `Adobe Acrobat` is required.

1.5 Look at IC Time Courses

```
> ########################################################
> #                Look at IC Time Courses               #
```

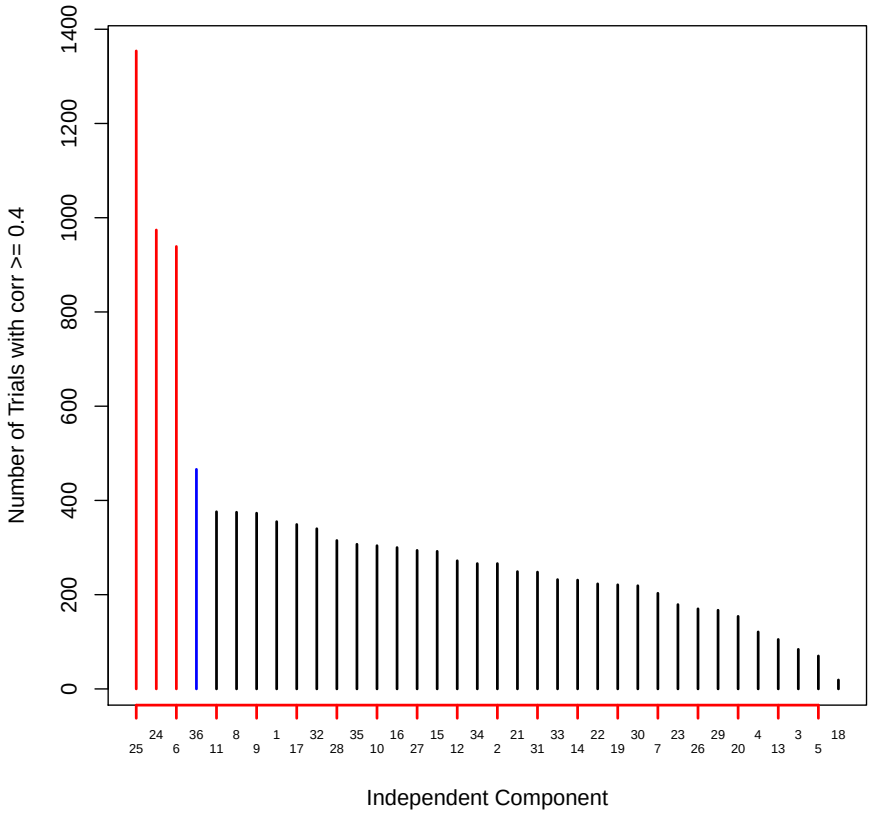

Figure 4. Number of trials with which each independent component (IC) correlated with above threshold.

```
> ###########################################################
> trials<-sort(unique(datc$data$Trial))
> trials<-epochs(trials,51,overlap=0)
> #
> # IC 25
> dir.create("figs/omega-11_ICs/time_courses/IC25",recursive=TRUE)
> for(tr in 1:length(trials)){
+         png(filename=paste("figs/omega-11_ICs/time_courses/IC25/trial",
+                 tr,".png",sep=""))
+         tmp<-trials[[tr]][1]:trials[[tr]][2]
+         plot_tric(datc,25,trials=tmp,n.win=length(tmp),new.page=FALSE)
+         dev.off()
+ }
> ### looks like its more blinks
> #
```

Figure 5. Scalp topographies of each IC. `Acrobat Reader` is required to play the animation. To play the animation, click on one of the "triangle buttons" right below the figure. The triangle pointing toward the left will play the animation backward. The one pointing to the right will play it going forward. The animation can be manipulated by clicking on the "<" and ">" buttons to move the animation one frame at a time backward or forward, respectively. The "|<" and ">|" buttons make the movie start from the beginning or go to the end, respectively. The "->|<-" button to the right restores the animation to it's default speed. The "-" and "+" buttons to its left and right make the animation go slower or faster, respectively.

```
> # IC24
> dir.create("figs/omega-11_ICs/time_courses/IC24",recursive=TRUE)
> for(tr in 1:length(trials)){
+         png(filename=paste("figs/omega-11_ICs/time_courses/IC24/trial",
+                 tr,".png",sep=""))
+         tmp<-trials[[tr]][1]:trials[[tr]][2]
+         plot_tric(datc,24,trials=tmp,n.win=length(tmp),new.page=FALSE)
+         dev.off()
+ }
> ### looks like some kind of noise
```

```
> #
> # IC6
> dir.create("figs/omega-11_ICs/time_courses/IC6",recursive=TRUE)
> for(tr in 1:length(trials)){
+         png(filename=paste("figs/omega-11_ICs/time_courses/IC6/trial",
+                 tr,".png",sep=""))
+         tmp<-trials[[tr]][1]:trials[[tr]][2]
+         plot_tric(datc,6,trials=tmp,n.win=length(tmp),new.page=FALSE)
+         dev.off()
+ }
> ### looks like eye movements
> #
> # IC36
> dir.create("figs/omega-11_ICs/time_courses/IC36",recursive=TRUE)
> for(tr in 1:length(trials)){
+         png(filename=paste("figs/omega-11_ICs/time_courses/IC36/trial",
+                 tr,".png",sep=""))
+         tmp<-trials[[tr]][1]:trials[[tr]][2]
+         plot_tric(datc,36,trials=tmp,n.win=length(tmp),new.page=FALSE)
+         dev.off()
+ }
> ### looks like drift mostly
> #
> ### so, I would remove the first three because they
> ### correlate a lot (more than others) with the EOGs,
> ### as well as the fourth one because of the drift,
> ### and the bad electrode, IC 18
```

1.6 Update Correction

```
> ############################################################
> #                    Update Correction                     #
> ############################################################
> datc<-update(datc,what=list(c(25,"-"),c(24,"-"),c(6,"-"),
+         c(36,"-"),c(18,"-")))
> save(datc,file="data/eeg/corrected/omega-11_CR_data_rshp_128Hz_
+         rrf_hp_bas_icac.rda")
```

1.7 Look at Uncorrected Versus Corrected EEG

```
> ############################################################
> #      Look at Uncorrected Versus Corrected EEG            #
> ############################################################
> trials<-sort(unique(dat$Trial))
> electrodes<-c(des("biosemi.32")$electrodes,
+         "TE","BE","LC","RC")
```

Figure 6. Time course of IC25. Mostly blinks.

```
> dir.create("figs/omega-11_uncorr_corr",recursive=TRUE)
> pb<-txtProgressBar(min=1,max=length(trials),style=3)
> for(tr in 1:length(trials)){
+         setTxtProgressBar(pb,tr)
+         png(filename=paste("figs/omega-11_uncorr_corr/trial",
+                 trials[tr],".png",sep=""),width=1920,height=960)
+         par(mfrow=c(6,6),mar=c(2.6,2.6,2.1,1.1))
+         tmp<-dat[dat$Trial==trials[tr],]
+         tmp2<-datc$data[datc$data$Trial==trials[tr],]
+         for(ee in 1:length(electrodes)){
+                 plot(tmp$Time,tmp[,electrodes[ee]],type="l",xlab="",
+                         ylab="",main=electrodes[ee],cex.axis=1.75,
+                         cex.lab=1.75,cex.main=1.75,frame.plot=FALSE)
+                 lines(tmp2$Time,tmp2[,electrodes[ee]],col=4)
+         }
+         dev.off()
+ }
> close(pb)
```

Figure 7. Time course of IC24. Some kind of noise that correlates with the EOG signals.

```
> #
> ### you can see how the blinks and a lot of the drift was removed
> ## by ICA.
```

Notice how `icac` not only removed blinks and eye-movements, but also drift. Note the y-axis changes somewhat from trial to trial, but in general the range is quite large (-200 to 200 μV).

1.8 Look at Corrected Data Only

```
> ##########################################################
> #             Look at Corrected Data Only                #
> ##########################################################
> trials<-sort(unique(dat$Trial))
> electrodes<-c(des("biosemi.32")$electrodes,"TE","BE","LC","RC")
> dir.create("figs/omega-11_icac",recursive=TRUE)
> pb<-txtProgressBar(min=1,max=length(trials),style=3)
> for(tr in 1:length(trials)){
+         setTxtProgressBar(pb,tr)
```

Figure 8. Time course of IC6. Mostly eye-movements.

```
+         png(filename=paste("figs/omega-11_icac/trial",trials[tr],
+                 ".png",sep=""),width=1920,height=960)
+         par(mfrow=c(6,6),mar=c(2.6,2.1,2.1,1.1))
+         tmp<-datc$data[datc$data$Trial==trials[tr],]
+         for(ee in 1:length(electrodes)){
+                 plot(tmp$Time,tmp[,electrodes[ee]],type="l",xlab="",
+                         ylab="",main=electrodes[ee],cex.axis=1.75,
+                         cex.lab=1.75,cex.main=1.75,frame.plot=FALSE)
+         }
+         dev.off()
+ }
> close(pb)
> #
> ### the amplitude range substantially diminished, which is good,
> ### but there still some alpha wave stuff. Could always remove one
> ### two ICs that seemed to have mostly parietal stuff in the alpha range
> ### with update the correction, I would probably leave it in.
```

Figure 9. Time course of IC36. Mostly drift.

Note the difference in trial-to-trial amplitude ranges, which is, in Figure 10, much smaller than in Figure 11.

Figure 10. Uncorrected (black lines) versus corrected (blue lines) EEG data.

Figure 11. Corrected EEG data only.